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THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

Simultaneous 3-Edge Cleaning Methods and Tooling Evaluation

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

in cooperation with
Peterson Builders, Inc.

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U. S. DEPARTMENT OF THE NAVY
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THREE-EDGE CLEANING

METHODS AND TOOLING

NSRP PROJECT #N7-92-2

FINAL REPORT

PRESENTED TO:

PETERSON BUILDERS, INC.

by

Paul A. Blomquist

Research Assistant
Applied Research Laboratory
Pemsylvania State University
P.O. Box 30
State College, PA 16804

Formerly: Senior Welding Engineer
Bath Iron Works Corporation
700 Washington Street
Bath, Maine 045330

November 20, 1995

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(*A complete list of names, adresses and telephone numbers of the organizations which have participated in this study appears in Appendix A, List of Resources.)

NSRP Project 7-92-2: Three-Edge Cleaning Methods and Tooling

Final Report

Table of Contents

List of Tables

List of Figures

THREE EDGE CLEANING METHODS AND TOOLING

NSRP Project ## 7-92-2

I. ABSTRACT

Equipment and technologies which could be used to simultaneously clean three surfaces of shipbuilding steels for subsequent welding operations have been surveyed. Two commercially available three-edge methods (closed circuit grit blasting and multiple-head wire brushing) were evaluated. Five other methods were tested: laser beam stripping, high-pressure water blasting, high velocity oxy-fiel (HVOF) flame stripping, vacuum-shrouded needle-gunning, and carbon dioxide (C02) bead blasting. Results of the survey are presented in a comparison table, and discussed in detail. For each method, production speed, approximate acquisition cost, consumables used, and environmental effects are considered. Where applicable, equipment was demonstrated at the manufacturer's or vendor's facility. A commercially available vacuum-recovery recirculating grit-blast unit was tested in a shipyard. The grit-blast unit was seen to be slower than manual grinding for three-surface cleaning. A flat-surface recirculating grit blast head proved significantly faster than manual grinding in the cleaning of butt joint grooves fit for welding with ceramic backings. Cleaned surfaces were examined by Scanning Electron Microscopy (SEM). Safety, environmental, and ergonomic aspects were reviewed.

II. CONCLUSIONS

- Multiple-brush machines clean faster than manual methods, but weight of the equipment limits its use, and may require two persons for lifting and moving, compromising the advantage.
- The current implementation of hand-held recirculating grit blast cleaning equipment is capable of producing ready-to-weld sutiace finishes, even on flange stubs of stripped I-beams.
- The vacuum recovery of these systems proved capable of collecting virtually all grit and waste products, and can provide a beneficial effect on shop air quality compared to traditional grinding or sanding.
- Single surface recirculating blast cleaning (with steel grit) of pre-fit groove butt joints proved to be significantly faster than manual grinding. The operation should be done before applying ceramic backings, using a temporary sealing tape on the opposite side of the joint.
- Scanning electron microscopy revealed that grit-blasted surfaces are substantially cleaner than those produced by traditional methods.
- Laser beam stripping achieved the most complete breakdown of coatings while producing significantly low levels of airborne metallic contaminants.
- Three-surface recirculating blast cleaning of plate edges with steel grit proved to be slower than manual grinding. Tests with aluminum oxide grit showed speed nearly equal to grinding.
- Noise levels produced by recirculating blast cleaning equipment are similar to those of other cleaning methods, requiring standard hearing protection.
- Three-edge cleaning equipment is heavy and awkward to use. Current designs may have sharp edges and corners, wide rollers may not function freely, and abrasion-resistant vacuum hoses are heavy and stiff, causing operator fatigue when cleaning long plate edges.

III. RECOMMENDATIONS

Based on the testing carried out in this project, the author cannot unequivocally state that any of the equipment surveyed is capable of cost-effectively replacing manual grinding in all situations *of pre-weld* edge cleaning, in which the contaminants to be removed are the typically thin (less than 0.001 in. [0.025 mm]) coatings of preconstruction primers and/or rust. Each method may offer a benefit in one area, but may require a trade-off in another area. The following generalities may be applied from the discussions which follow in this report.

- If shop air quality is the overriding concern, closed circuit grit blasting can provide exceptionally clean surfaces with virtually no emission of dust or grit. Aluminum oxide grit can provide cleaning rates competitive with manual grinding, but grit costs more initially and wears out faster than steel grit.
- If overall surface cleanliness is the paramount concern, grit blasting provides an arguably superior surface condition for subsequent welding.
- If the material can easily be moved through a stationary head, the larger mechanized grit blasting machines work well.
- Portable closed circuit grit blasting equipment should be thoroughly redesigned. Heads need to be made with smooth contours to provide for safer, more comfortable operation. Nozzle adjustments with better control of blast pattern location and width, and guide rollers which operate more smoothly need to be incorporated. If possible, lighter and more flexible hoses need to be used to reduce operator strain.
- If the parts to be cleaned can be positioned for good access with the edges pointing vertically up, multiple-brush machines can be effectively used at a speed improvement over manual grinding. Some type of load balancer could be used to allow a single operator to lifl and move the machine from part to part. If a second person is needed, much of the speed advantage is compromised. The multi-brush units may leave primer in the radius areas of flange stubs of deflanged I-beams (I/T shapes).
- *Forpre-weld* cleaning, the five other technologies surveyed (C02 bead blasting, laser beam paint stripping, high pressure water blasting, HVOF paint stripping, and vacuum shrouded needle-gunning) cannot be considered competitive at this time, for various reasons, including speed of operation, affect on the part final condition, or overall capital cost of the equipment required. Each of these methods has secured a niche market in other cleaning applications, and further development and market conditions may allow one or more of them to become competitive for pre-weld cleaning.

One area in which further work should be done is the evaluation of the effect of surface condition on arc stability and overall welding speed. A brief test seemed to confirm the plausible conclusion that grit-blasted surfaces, with a profusion of sharply pointed features, will allow a more stable arc to be established, and progress at higher speed, with less spatter. Abrasive methods “smear” peaks over valleys, trapping residual contaminants, and promoting a more erratic arc as the features melt away. Where high speed is used to reduce weld size and control distortion a grit blasted surface may provide a substantial benefit to both weld quality and accuracy.

IV. BACKGROUND

A fundamental necessity of welding is that the materials to be joined must be "clean." In other words, we must remove any substance which could adversely affect either the process of welding -- the dynamics of the arc, the wetting and formation of the weld puddle -- or the product -- the physical and metallurgical structure and properties of the final weld.

Beyond the issue of mere good judgment, most fabrication codes demand that potential contaminants be removed from the weld zone. The language maybe more explicit in some and less stringent in others. Further, most standards require that the cleaning include not just the actual weld zone, but extend some arbitrary distance away from the anticipated toe of the final weld.[1,2,3,4] Typically, potential contaminants are required to be removed: in the case of preconstruction primers and some other preservative coatings, a special approval based on qualification testing may be required before welding is allowed without removal of the coating.

When preconstruction primers are qualified for use, the steel plates and shapes are usually stored outside until needed. The material is loaded onto conveyors and fed into a mechanized blast and prime facility. An aggressive grit is usually used to remove mill scale and rust, and the surface produced may have a profile of substantial depth. Primer is applied and dried as the plate moves continuously along the conveyor. Motion of the paint guns across the plate is adjusted relative to the line speed so that a thin, even film (typically less than 0.001 in. (0.025 mm) is applied. Film thickness is frequently checked to assure compliance to the qualified welding procedure, but the typical measuring instruments (magnetic gauges) usually sense the amount of primer above the peaks of the blast profile, and are not sensitive to the amount of primer in the valleys of the surface.

The use of preconstruction primers on shipbuilding steels is a series of trade-offs. One benefit is that in-process material can be stored outside for a limited time without significant rusting. Other advantages are that the primers provide a good surface for layout marks and piece marks, and resist the adhesion of weld spatter, reducing cleanup time prior to final painting. The disadvantage is that primers are, by their very nature, at cross-purposes to welding. Pigments, binders and fillers of these "weldable primers," while selected to have a minimum impact on weld quality, nonetheless do affect the welding process. The same feature that prevents spatter from sticking also causes instability of the arc and interferes with the wetting of the weld puddle into the base metals.

Thus even when welding through a preconstruction primer is qualified, there may be circumstances where removal of the coating is advisable. Increasingly, shipyards are looking to high-speed mechanized welding for improved production and reduced distortion. When attempting to weld through primers at high speeds, arc instability and poor wetting cause erratic weld bead contour, especially at the weld toe. Further, the volume of gas generated by the breakdown of the common primers may exceed the ability of a fast-freezing weld pool to out-gas, with resulting porosity, in amounts from a nuisance level to severe. Both poor contour and porosity can be the cause of significant rework, which affects both the cost and schedule performance of building ships.

There are only two remedies for this problem: slow down the process, and risk increased distortion, or remove the primer. Both take time. If an efficient means of precleaning is available, the fill benefit of high speed mechanized welding can be realized. Although the development of primers and filler metals for primers may alleviate this problem, so far there has been little progress in this arena.

Typically, there are three surfaces of each member to be joined which will require attention, as shown in Figure 1. Butt joints need to have the upper and lower surfaces of the plates cleaned, as well as the joint faces, which maybe square or beveled. Stiffening members which will be fillet welded to plates must have contaminants removed from both faces and the faying (contact) surface as well. Stiffeners may be made from flat bars, hot-rolled shapes such as angles and tees, or shapes built up from plates. A special case unique to shipbuilding is the "I-to-T" (I/T) or "stripped I-beam," a tee shape produced by removing one pair of flanges from a hot rolled I-beam. This shape poses a special challenge due to its typically discontinuous configuration near the weld zone, as shown in Figure 2. This configuration results from the fact that the stripping process (typically OxY-Fuel Cutting) cannot cut the flanges flush to the web without damaging the web, and torches are therefore positioned to leave a portion of flange material ("flange stub"). How well a method can clean this radius area is important, as well as the ability of the seals of vacuum recovery devices to conform to this shape.

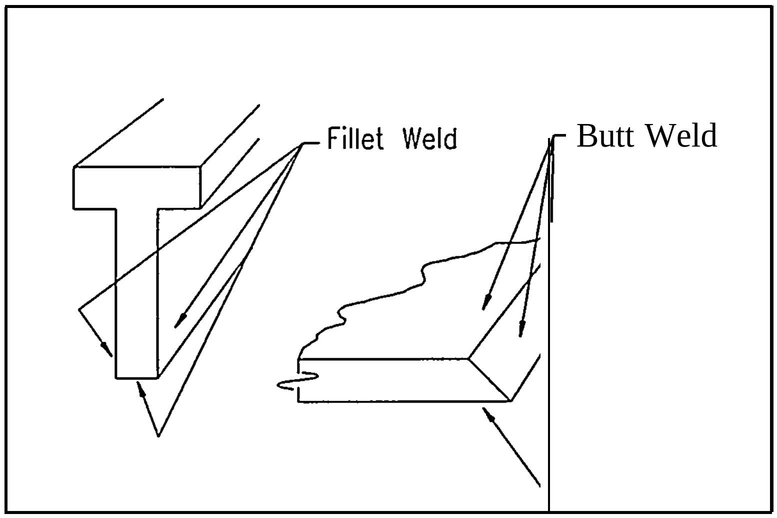


Figure 1. Surfaces requiring pre-weld cleaning

Traditionally, manual grinding or sanding (see Figure 3, next page) has been used to clean these surfaces. The tools required are simple and relatively easy to operate and maintain. Manual grinding has two shortcomings: first, the material must be turned over to gain access to the opposite side, a time-consuming operation for large pieces, or the grinding tool must be operated in an inverted position, which can be dangerous; second, all of the swarf -- the by-product of grinding -- is thrown a great distance into the air. This includes the surface contaminants such as paint, rust, and scale, bits of base metal, and the dust from the grinding wheel, which can be composed of metallic oxides, resin binders, fibers, and other materials.

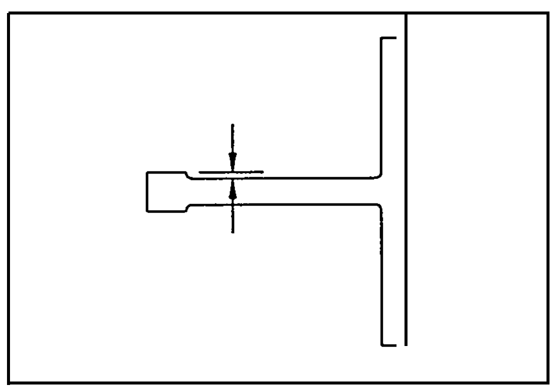


Figure 2. Edge configuration of VT

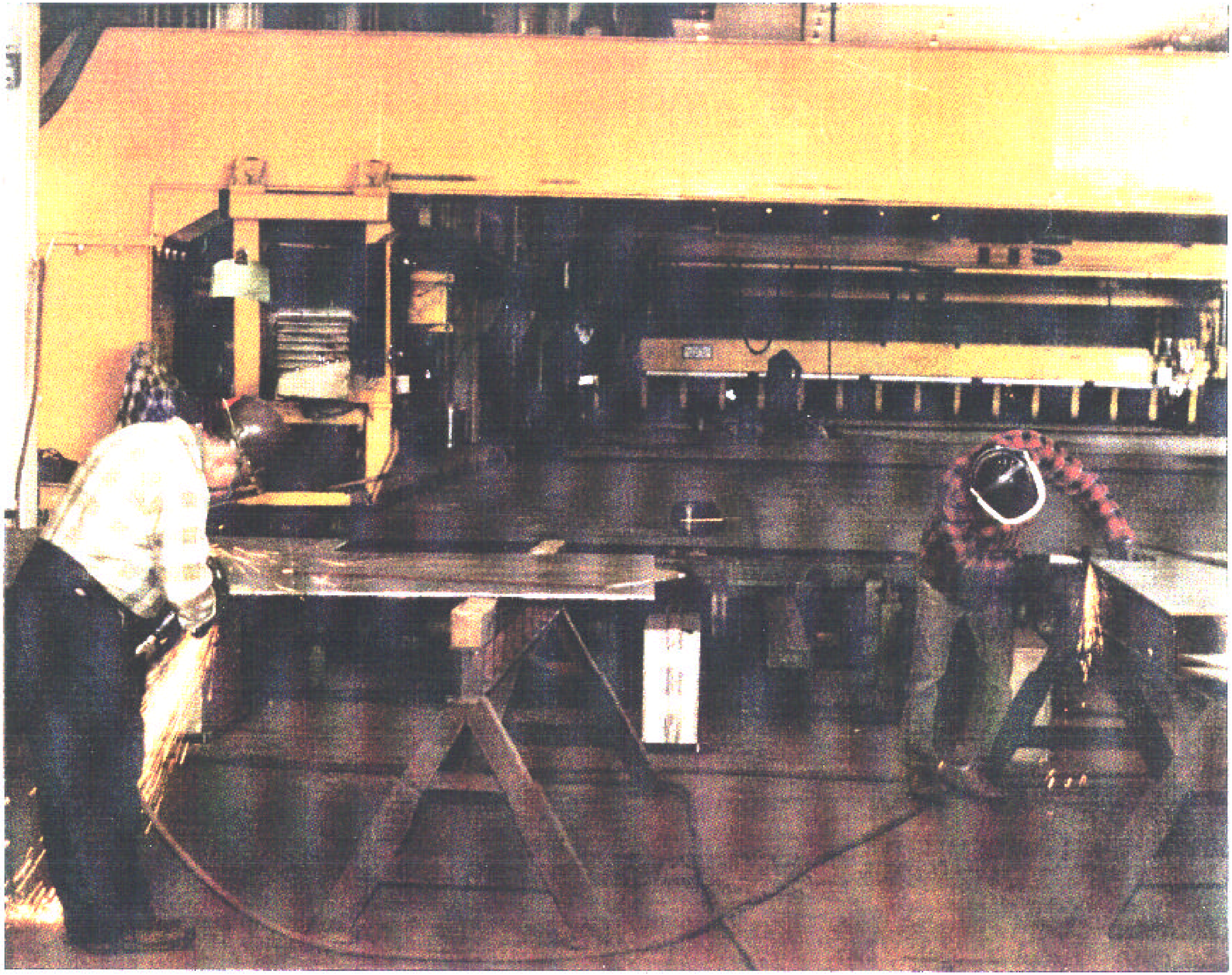


Figure 3. Manual grinding of plate edges prior to butt welding

If the cleaning operation could be done with a device which would clean all three surfaces simultaneously in one pass, an improvement in productivity will result if the method can work at a sufficient speed. Further, if the method is amenable to some form of recovery (vacuum etc.) of the swarf then significant improvements to the air quality of the shop can be realized. As Permissible Exposure Limits (PELs) of various substances in the workplace get lower and lower, this aspect may become more significant than the issue of production rates.

V. TECHNICAL APPROACH

The aim of this project was to evaluate technologies which have the potential for simultaneous three-edge cleaning, and establish the speed, cleanliness, and potential for environmental improvements which they offer. Accordingly, the following steps were taken

- survey current three-edge cleaning technologies,
- survey cleaning technologies with potential for three-edge cleaning,
- where possible, have the manufacturer or vendor demonstrate the equipment, using shipyard material, and perform relevant environmental testing,
- rent a commercially available recirculating grit blasting unit equipped with three-edge gun for evaluation on a shipyard panel line,
- secure a review of environmental and ergonomic data by a Certified Industrial Hygienist, and
- use Scanning Electron Microscopy to examine surfaces produced by the various methods.

At the time this project was begun, two devices which could simultaneously clean three edges were commercially available: vacuum recirculating grit blasting equipment and multiple-arbor wire brush units. The multi-brush units had been used in a production capacity at Bath Iron Works Corporation% so that performance features were fairly well understood.

The program was not intended or funded to allow detailed quantitative data to be generated for all of the methods reviewed. Rather, the salient features of each were examined, and the positive or negative aspects qualitatively evaluated. Furthermore, the wide variety of locations for these evaluations made it difficult if not misleading to compare all of the data on a one-to-one basis. This is especially true of the environmental and ergonomic aspects of the equipment reviewed. Such things as background conditions at the test locations can have a great influence on test results, and thus the shipyard environment can only be approximated at a typical vendor’s facility.

After a survey of technologies and review of the equipment available, a suitable recirculating grit-blasting unit, (shown in Figure 4) was selected for an evaluation in a shipyard panel lime.

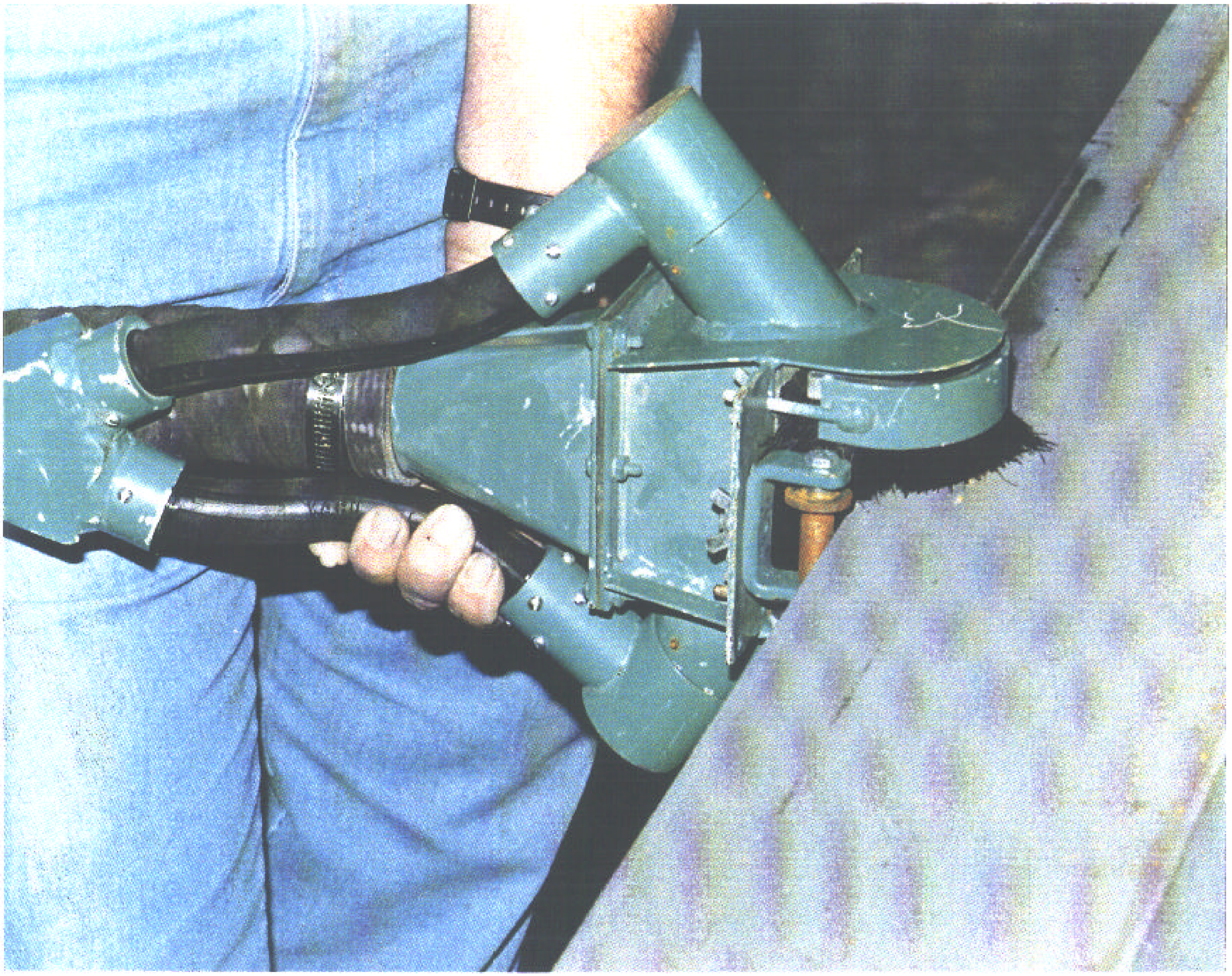


Figure 4. Three-edge head of vacuum recirculating grit blast system

VI. EQUIPMENT REVIEW

The purpose of the equipment review phase was to determine the suitability of potential technologies and machinery which could be used for cleaning three edges of plates, hot-rolled shapes or stripped I-Beams. Therefore, this phase addressed these questions:

- Can the method or tool sufficiently clean three adjacent surfaces in one pass?
- What are the possible production rates?
- What are the acquisition and consumable costs for the equipment?
- What are the potential environmental effects and ergonomic aspects?

In this survey, seven methods have been considered, as summarized in Table I: multiple-head wire brushing; closed circuit grit blasting high velocity oxy-fiel (HVOF) flame stripping, vacuum-shrouded needle-gunning, high-pressure water blasting, carbon dioxide bead blasting, and laser stripping. Of these, only multi-brushing and grit blasting have been used for three-sutiace cleaning. This equipment is currently available for purchase, but not is widely used. The other methods have been used for the purpose of paint or contaminant removal from single flat surfaces, or at most from two adjacent surfaces, in various situations.

TABLE I . CLEANING METHODS/EQUIPMENT

Process	3-Edge Speed*	cost	Consumables	Environmental Aspects
Three-edge methods				
Multi-head wire brushing	5-10 fpm (1.5-3 m/min.)	$5K	Brushes, Air	Not yet integrated with vacuum recovery.
Closed-Circuit Grit Blasting	6-20 fpm (1.8-6 m/min.)	$50K	Grit Air	Vacuum recovery widely used on flat plate, 3-edge tooling long available, but not widely used.
Single or Two-surface methods				
Water Blast	Untried on multiple edges	$90K	Water, Power	Not yet integrated with vacuum on other than single surfaces.
HVOF Flame Stripping	Untried on multiple edges	$10-25K	Gas	Some application on non-metallic surface treatments. Not integrated with vacuum
Laser stripping	Untried on multiple edges	$300K (Nd:YAG)	Power, Gas	95'%o Reduction of solids to ash demonstrated. Not yet integrated with vacuum on multiple surfaces.
C02 Bead Blasting	Untried on multiple edges	$30-50K	Air, C02 Pellets	Experience with single-surface cleaning of lead-based and other contaminants. Not typically integrated with vacuum
Vacuum-shrouded needle gun	Untried on multiple edges	$2K Up depending on config.	Air	Experience on single- and two-surface cleaning of lead-based coatings
*Speed depends on amount of paint,rust,etc. to be removed, and desired final appearance				

Where ossible, several vendors of each type of equipment were contacted, but it was not practical within the constraints of the project to attempt to discover all possible vendors whose equipment might be adapted to the cleaning of multiple adjacent surfaces simultaneously. Thus it should not be considered that the sources reported here are necessarily the best or the only ones for the type of equipment under consideration.

The following summaries, drawn from discussions with manufacturers and vendors, provide a brief description and photographs of the equipment evaluated and the trials perllormed. Surfaces produced by some of these cleaning methods were examined using a Scanning Electron Microscope (SEM), and are discussed in Section VII. Detailed ergonomic, safety, and environmental analysis of the equipment evaluated is provided in Appendix B.

For most of the tests, shipyard structural shapes and plates coated with a nominal 0.8 mil (.02mm) film thickness of inorganic zinc (IZ) preconstruction primer (PCP) were used. The particular primer, “International Ferro-Phos NQA 203” contains approximately 35% zinc. A smaller number samples, coated with “International NQA 993 Nippe-Ceramo” primer (having a nominal zinc content of 40%) were noted to respond to cleaning in a fashion similar to the NQA 203. Thus in this report, both primers are subsequently referred to as IZ-PCP. Two specimens coated with a water-based epoxy PCP (“Ameron 3207”) were evaluated using both closed circuit grit blasting and C02 pellet blasting.

Closed Circuit Grit Blasting

Equipment for vacuum-recovery recirculating grit blasting was originally built in the United States in the late 1940’s. The first reported device to simultaneously clean three surfaces was developed by the Vacu-Blast Company, then of California, for pre-weld joint cleaning on pipeline construction projects. This head was later redesigned to add guide rollers and a single vacuum recovery chamber. Figure 5 shows both the older and newer style of head; Figure 6 is a close up of the newer style head, showing the guide rollers and seal brushes.

Three vendors of equipment were surveyed: Vacu-Blast International (VBI), from the United Kingdoxq and the U. S. companies Kelco Sales and Engineering, and ABB Raymond Blasting Systems (ABB). All three companies manufacture a wide range of blasting equipment from portable units to enclosed booths. VBI and ABB manufacture total three-edge systems, but were unwilling to offer a system to evaluate on a rental basis. Kelco manufactures certain blasting systems (not three-edge equipment), but was able to provide a three-edge rental unit for these tests. Although VBI and ABB have marketed three-surface cleaning devices for a number of years, not a lot of systems have been sold. In other industries, such as highway bridge maintenance, interest in single- and two-surface closed-circuit blasting has escalated sharply due to more stringent environmental rules, but simultaneous three-surface treatment has not been a necessity. Steel fabrication, in contrast, is only now becoming an area where attention to air quality may focus greater interest on closed circuit blasting, Since the material requiring cleaning is “new,” and therefore the coatings comply with current regulations, issues such as those encountered for the safe and clean removal of lead-based paints do not usually occur.

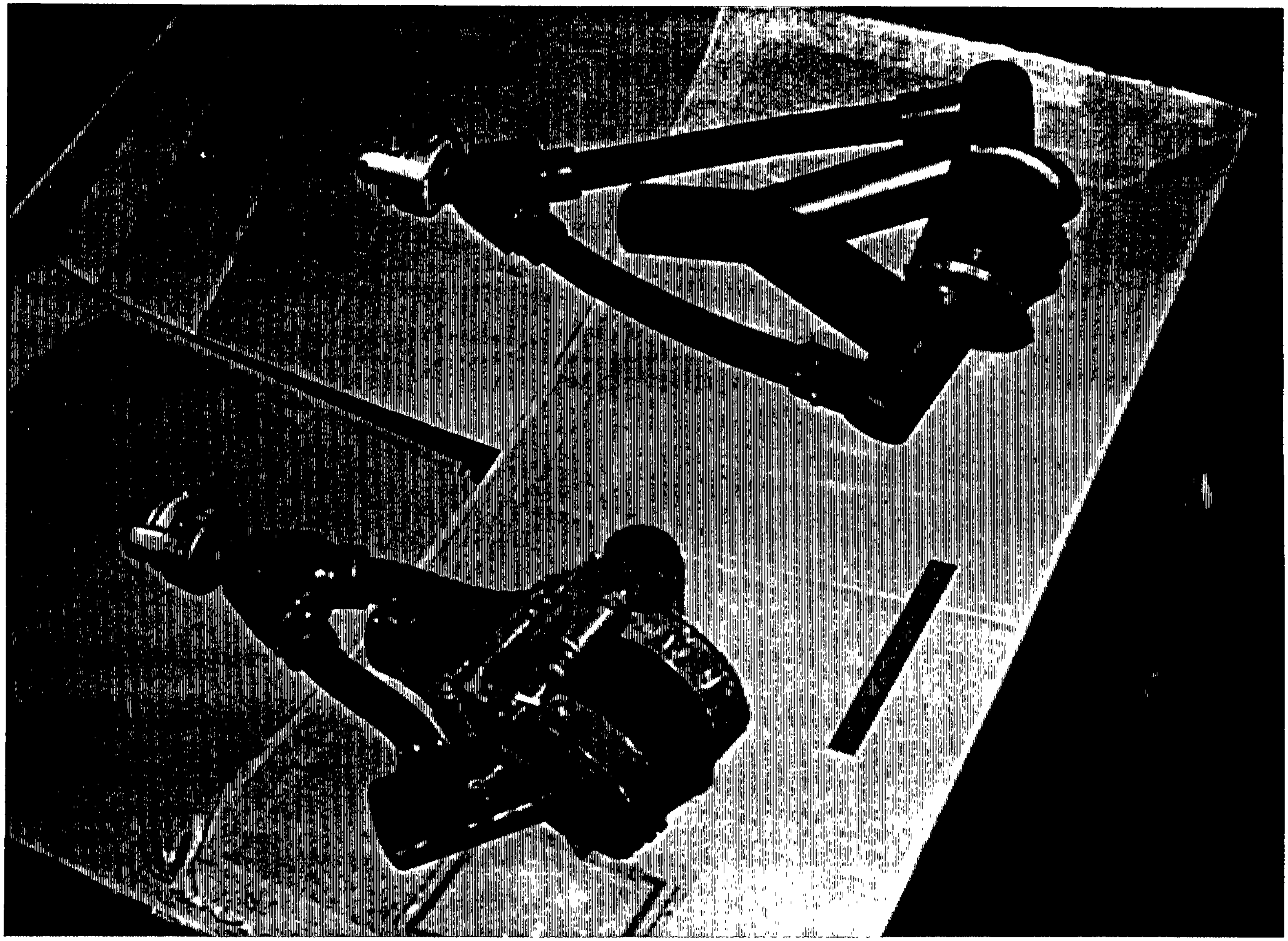


Figure 5. Top: original design head; bottom: newer-style three edge head .

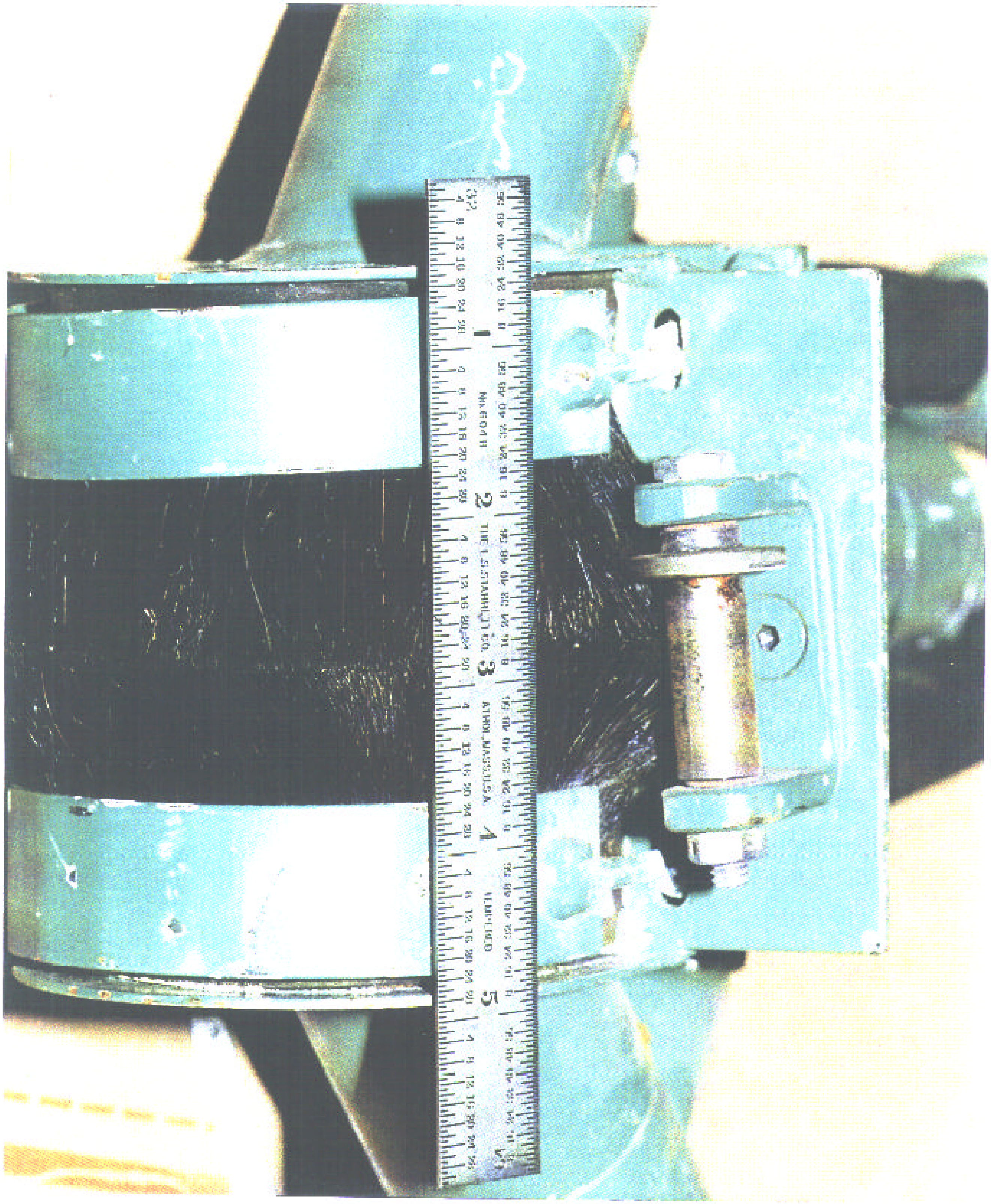


Figure 6. Close-up of newer-style three edge head.

Closed circuit grit blasting systems can cost from around $20,000 to over $50,000, depending on the parameters of the blasting and vacuum systems, whether the system is continuously or batch-fed, and the length of hoses from the system to the point of operation. Shot and grit which are suitable for recycling, such as steel, iron, or alumina are typically used. These are usually more expensive than coal slag or more friable grits. Also, the capacity of the holding tanks and the time required to replenish grit area factor in the operational cost of consumables, since a grit such as aluminum oxide may clean faster but will breakdown more quickly than steel. Power for vacuum systems or compressed air is not usually a major cost.

Data from VBI quoted a production rate of approximately 3-7 fpm. (1-2m/min), and undocumented sources quoted a potential for up to 20 fp(6 m/min). Obviously, plate condition and the degree of cleanliness required will have the greatest affect on travel speed for a particular system. Nozzle design and orientation can be a factor, as well as many of the attributes of the air and grit supply system so that the only useful, method of assessing performance was to do a trial with shipyard materials, in a shipyard environment. This was done in a later phase of this project.

Three-edge blasting equipment is relatively simple grit from a holding tank is metered into a compressed air stream feeding the head. Near the head, the incoming grit is diverted into two nozzles which are aimed at the intersecting comers of the three surfaces. A powerful vacuum source connected to the head cleans up all the grit and swarf, transporting them to a “cyclone” chamber, which allows larger (re-usable) grit particles to be recycled, while smaller (worn) grit particles and other removal products are pulled out and dropped into a waste chamber. Filter bags capture fine dusts. In batch fed units, recycled grit is held until blasting stops, when a check valve opens to allow the grit to fall into the grit tank. Continuous-feed units are usually much larger, and the grit returns to the supply tank automatically. There are differences in total grit capacity, length of hoses, nozzle design, impingement angle, and vacuum systems, but the basic concept is the same. Choice of angle and nozzle shape are based on development work and experience. The unit rented from Kelco (see Figure 7) for these trials is typical. The arrangement of hoses, control valve and blast head is shown in Figure 8. Figure 9 shows the unit in operation.

Site trials of this portable equipment were performed at VBI, ABB, and Kelco. The trials at ABB and VBI consisted of simple tests on available material, cleaning not more than ten feet of accumulated length. VBI arranged for a visit to the Harland and Wolff shipyard in Belfast, Northern Ireland, where a large continuous feed mechanized system was observed in operation.

Since closed-circuit blasting has been used to remove lead-based paints, the capability of blast head brush seals, filters, and containment to control dust emissions when used on flat surfaces and comers is fairly well developed. For this project, the coatings to be removed are not generally considered to be significant hazards, so that disposal of the spent grit and the separated dusts should be less of a problem although it should not be considered to be trivial. Of greater concern is the integrity of the sealing around the flange stubs of the I/T shapes mentioned earlier. For the trials at Kelco, where a large quantity of material was cleaned, testing of airborne dust in both general area and breathing zone were performed. At all three locations, noise levels were measured, and were found to range from 90-110 dBA, which is consistent with noise levels produced by traditional grinding/sanding processes.

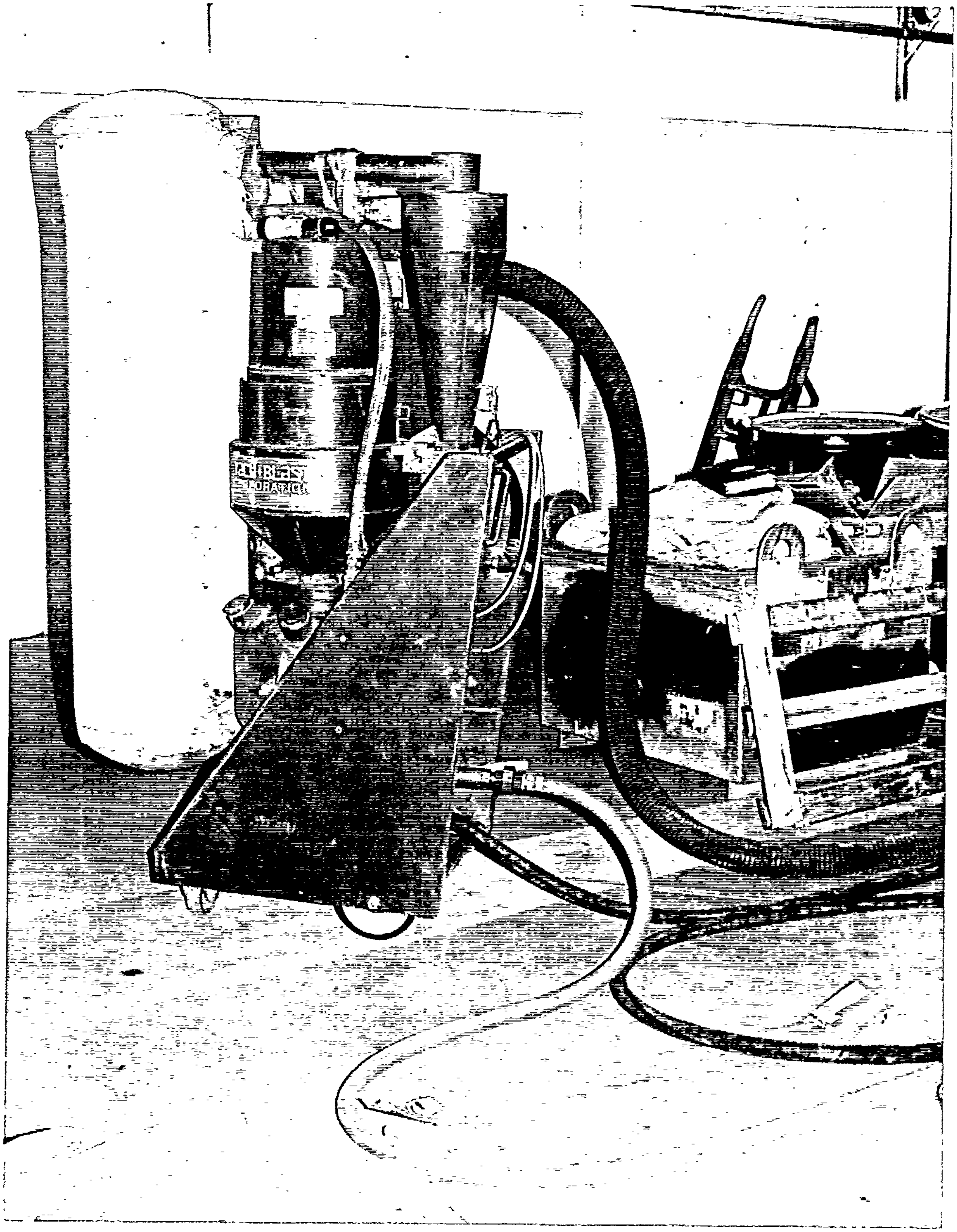


Figure 7. Vacu-Blast Unit supplied by Kelco Sales & Engineering. From l-r: dust bag; grit tank (lower) and grit separator (upper); cyclone dust separator. Foreground red hose is air supply, small black hose is air/grit feed, and ribbed black hose is vacuum recovery.

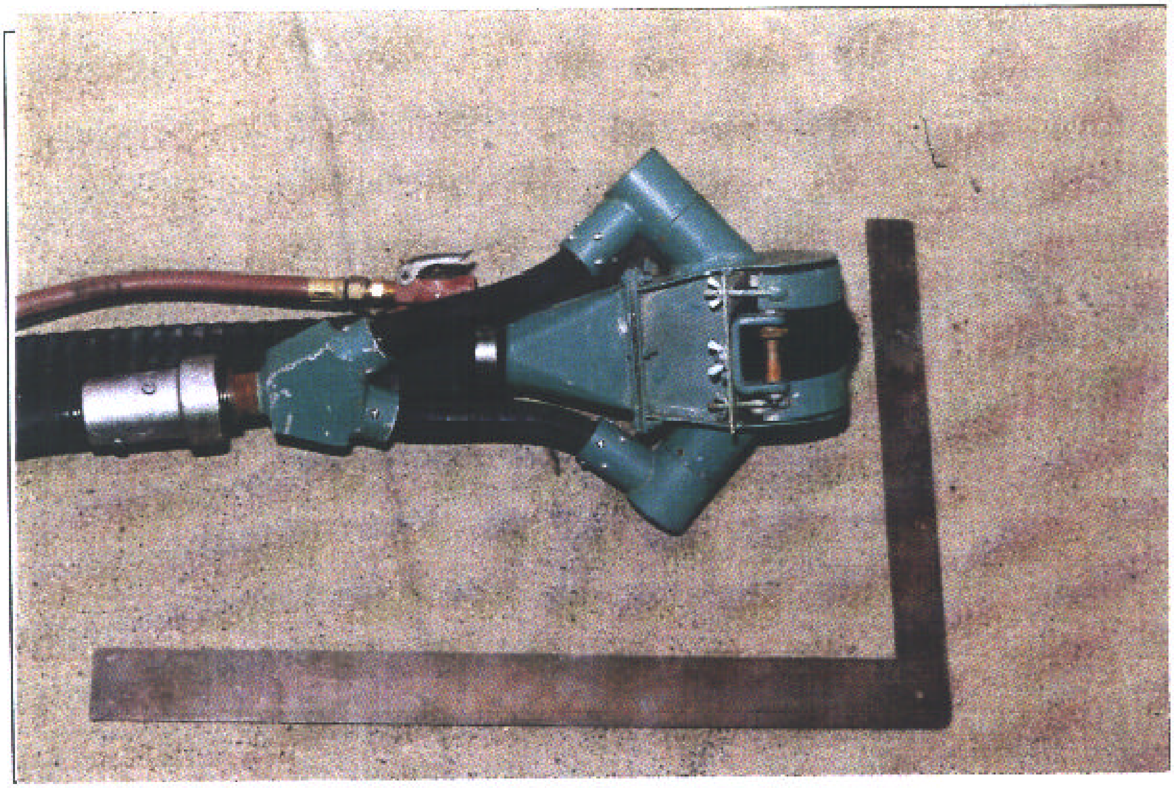


Figure 8. Newer style three-edge head, showing hose arrangement and control valve.

Figure 9. Three-edge gun, removing rust and IZ-PCP from web of Tee.

A significant quantity of material (more than 700 feet [213 m] of accumulated length) was tested at Kelco to evaluate different gun models, establish production rates for various types of grit, and perform noise and airborne contaminant tests. Sampling for airborne contaminants in the general area and operator breathing zone showed excellent capture of removed material (see Appendix B). Travel speeds from approximately 40-110 ipm. (1. O-2.8m/min) were noted, with averages of 54 ipm (1.4 m/min.) for steel grit, 81 ipm (2.0 m/min.) for aluminum oxide grit, and 83 ipm. (2.1 m/min.) for a relatively new ferrous oxide grit having the trade name of "CrystalGrit." While the CrystalGrit performed better than alukina, it, too, was subject to rapid breakdown. Results of tests at Kelco Sales and Engineering are summarized in Table II. The pieces for these trials were mostly coated with IZ-PCP, and slower speeds were experienced on a limited number of pieces primed with water based epoxy PCP. Figures 5-9 show the equipment tested at Kelco.

The weight of the head and the stiffhess of hoses caused substantial back strain for the operator. A temporary shoulder strap, fashioned from cloth strip and taped to the head and hoses allowed the operator to assume a more erect and codortable posture, putting the load more on the knees. Another "nuisance feature" was that the newer head had sharp comers which caused significant discomfort. Gloves with extremely long gauntlet portions, extending far up the fore- were required to provide protection. Finally, the guide rollers did not roll smoothly, and contributed to ematic motion along the edge, especially on I/T shapes which might have residual burning slag from the deflanging operation. When good contact and alignment was maintained, the machine produced very clean surfaces, even on the flange stub radius areas.

The mechanized VBI three-edge blast machine at the Harland and Wolff shipyard was operating at approximately 84 ipm (2.1 m/min.), producing an exceptionally clean surface for welding. Figures 10 and 11 show the machin; Figure 12 is a close-up of the edge of the bulb flat after removal of the primer. The primer was being removed because it caused porosity and poor contour in submerged arc fillet welds made by the shipyard's mechanized panel line welding equipment.

Table II. Vendor Site Trials
(Kelco Sales & Engineering, Norwalk, CA)

Blast Media - Coating	Length (m)	Time (min.)	speed ipm (m/min)	Remarks
Steel Grit - IZ-PCP	**4,193 (106.5)**	*81.9*	51.2 (1.3)	*34* total pieces various thickness plate, T, and I-beam sections. Max. length of longest individual piece, 139 in. (3.5m), all edges of each piece cleaned
Steel Grit - Epoxy PCP	**333 (8.5)**	*7.3*	45.6 (1.2)	
Aluminum Oxide - IZ-PCP	2,354 (67.5)	*28.9*	81.7 (2.1)	
CrystalGrit - IZ-PCP	1,669 (49.3)	17.5	*95.4 (2.4)*	
CrystalGrit - Epoxy PCP	271 (7.7)	5.7	*47.5 (1.2)*	

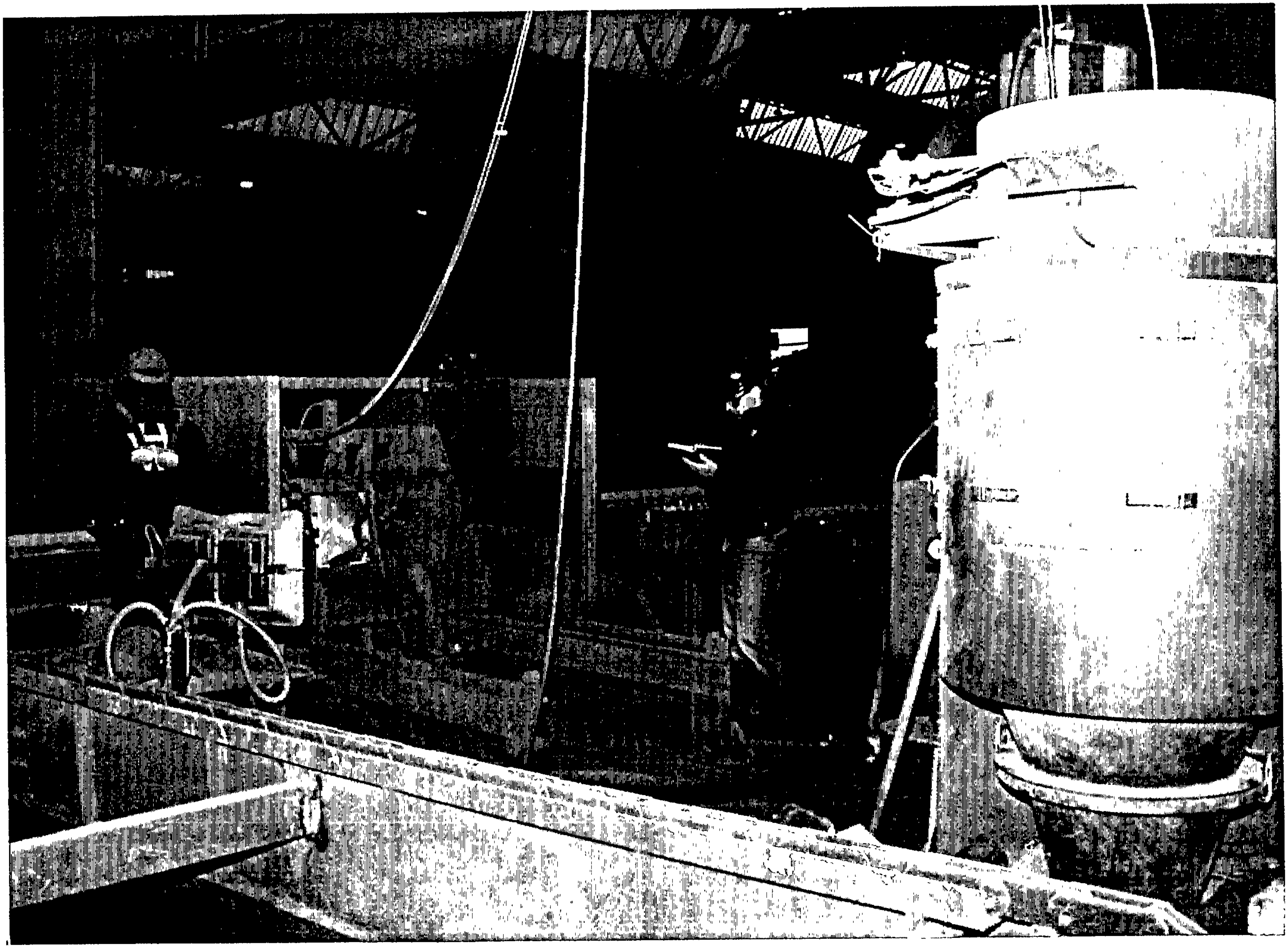


Figure 10. Vacu-Blast International automatic three-edge blast cleaning machine .

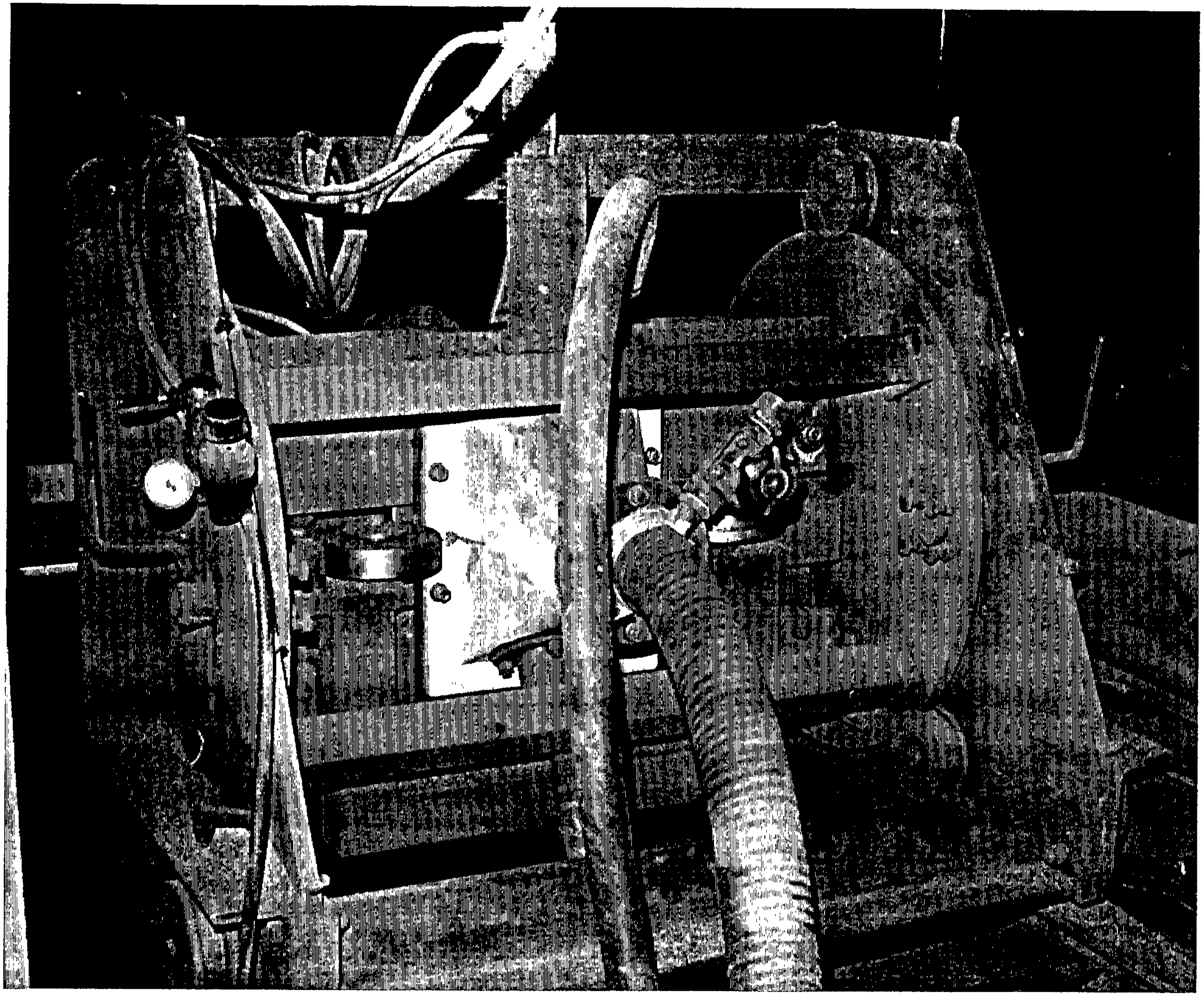


Figure 11. Blast head of VBI automatic unit (portion of bulbed flat at extreme right).

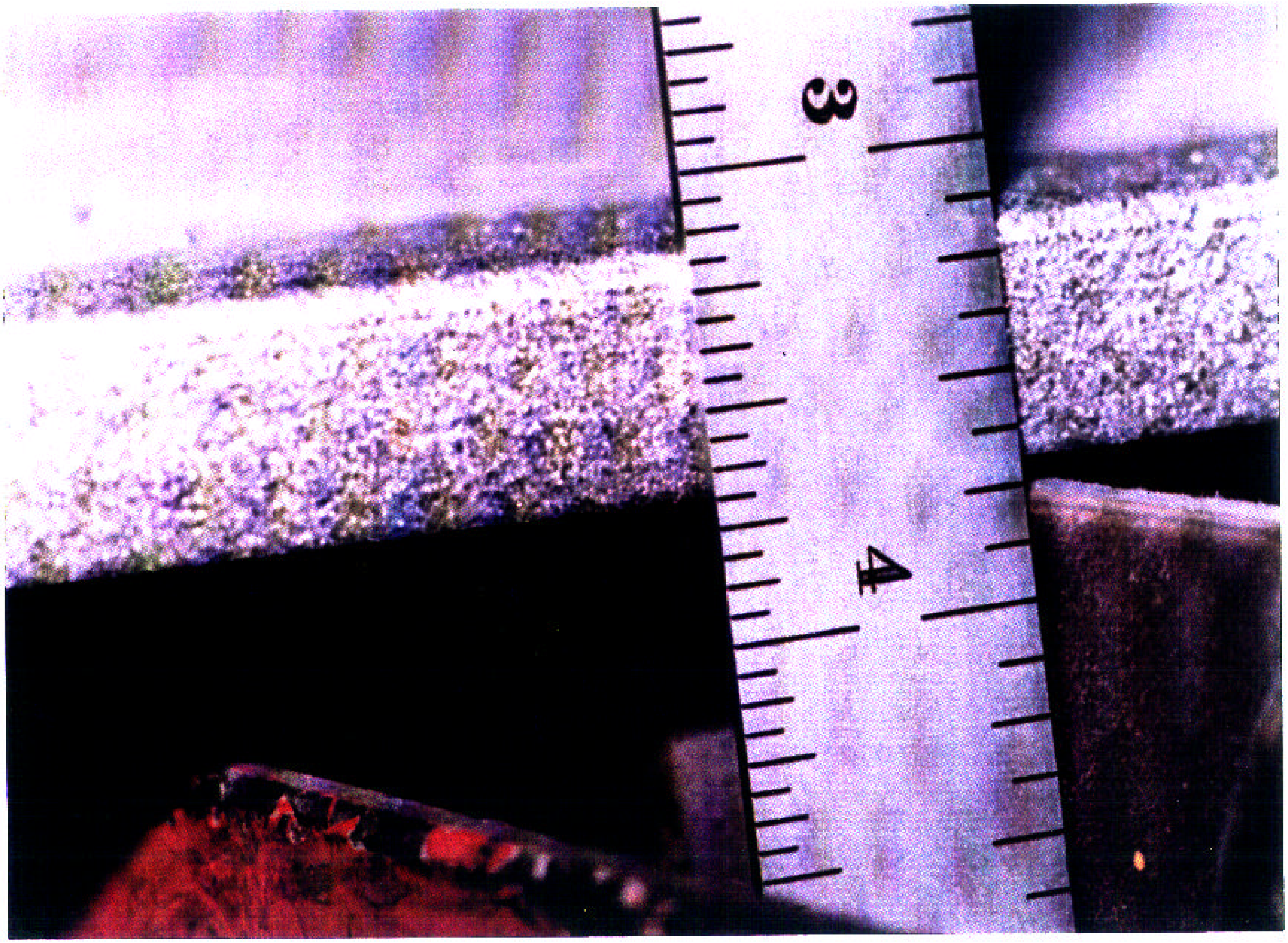


Figure 12. Close-up of faying edge of bulbed flat after blast cleaning .

Multiple-Head Wire Brushing

The “Double Edge Web Scaler” has been available from Desco Manufacturing Company for several years. The standard machine (Figure 13), with two brushes shrouded within a housing, cleans all but the faying surface of a Tee-section web (refer again to Figure 1, page 3). The optional version has a third brush unit mounted so as to clean the faying surface. Bath Iron Works has used a three-brush device for about 10 years, principally to clean the Tee-bar surfaces, with the bar in an inverted position (web up). The machine weighs 60 lb. (27.2 kg), not counting the added weight and drag of air hoses, but has rollers which track the web easily. The weight adds enough inertia to allow the unit to be operated in a stable manner as it is pulled over the bar. It has thus far not been used for the plate edge application shown in Figure 1, mostly due to its weight, the lack of symmetry for this position and the fact that brushes are exposed when the unit is turned on its side. The machine is not designed to clean weld joint bevel faces. Typically, a 50 foot (15.2m) Tee bar or other suitable structural shape may be cleaned in five to ten minutes, for a travel speed of up to 10 fpm (3 .05 m/min.). OSHA regulations may require a second person to assist in moving the unit from one part to another, so some of the speed advantage is lost.

The machine runs on compressed air and costs from $4,000 to $5,000. Typically, wire brushes are relatively inexpensive and durable. Other rotating abrasive materials (such as the “3M Roto-Peen”) may offer improved performance on mill scale or different coatings. The machine is not available with any sort of vacuum recovery to collect the swarf, although such modifications could be easily made. Obviously, weight would be increased, and some sacrifice in mobility might result. A significant factor is the amount of momentum given to the swarf by the brushes, and the degree of sealing and suction necessary to prevent leakage. Since the swarf particles (bits of steel, rust and preconstruction primer) are not viewed as critical hazards at this time, there is little incentive to make changes to a relatively simple, functional, and reliable piece of hardware. Because this machine uses traditional air-driven wire brushes, the noise levels and airborne contaminant experience are consistent with current general shop conditions in a typical shipyard environment, and were not specifically evaluated.

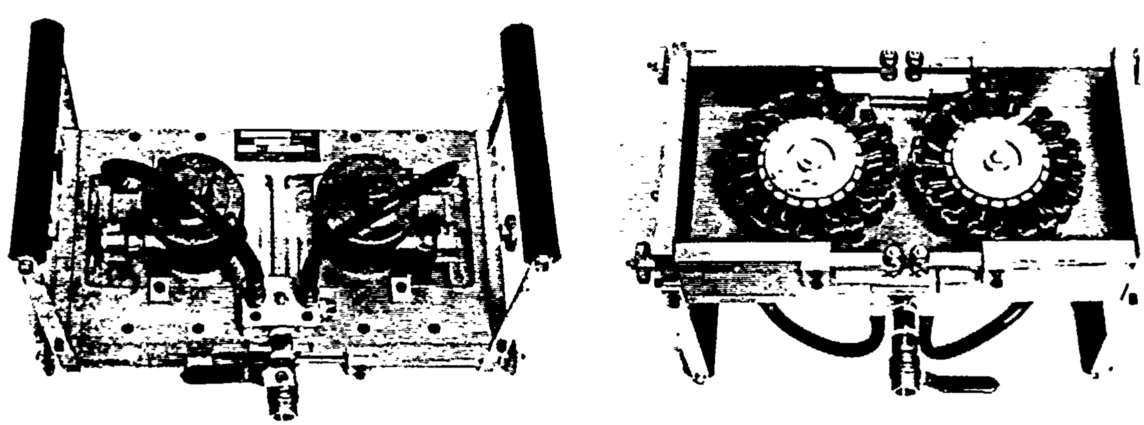


Figure 13. Desco Double-Edge Web Scaler. Third head (not shown) is a factory-supplied option. (Photo courtesy of Desco Manufacturing Company, Incorporated.)

Laser-Beam Paint Stripping

Laser-beam coating removal is currently being investigated in many efforts nationwide, since the method offers good control over depth of penetration allowing intense heat to break down a coating with minimal effect on the substrate. Work has been done on lead-based paints and other coatings such as anti-fouling paints and epoxies. In these situations, such as ship overhaul or decommissioning, coating thicknesses are greater than those used with PCP'S.

A *3* kW Nd:YAG laser system costs approximately $300,000, which includes the laser source, fiber optic cabling, and chiller, not counting devices needed to move or manipulate the laser beam. Primer coatings, being thinner, would require less power to remove, allowing the use of less expensive, lower-powered equipment. Electricity is the major consumable. Since Nd:YAG lasers are about 3% efficient, a 3 kW device requires 90-100 kW of input power. The use of oxygen to aid in breakdown of organic compounds adds a small amount to the cost. Since cable lengths of up to 49o ft (150m) are possible, there is better access to a range of work areas in contrast to the relative "inflexibility" of traditional mirror and hard-optic beam manipulation used by C02 lasers.

An interesting possibility is the prospect of mounting a laser device on the head of a mechanized welding tractor, to clean surfaces "on the fly," just prior to welding. It is entirely possible that residue from laser stripping of PCP's is an acceptable surface for subsequent fillet welding. One reason for the removal of primers is that they interfere with high speed mechanized fillet welding (even though welding through the specific primer has been qualified by testing), because arc instability and porosity occur. In this case, having removed the primary source of porosity and the major dielectric component of the primer (organic binders and fillers), welding should be possible and allowable. Testing can verify this, and can also determine if the residual ash poses problems for butt welds, although approval for butt welds may be difficult to obtain. Of further concern is the protection of personnel from laser radiation, but this can be achieved through safety interlocks which prevent laser activation unless the device is completely engaged on the part being cleaned.

Given the current cost of lasers, this may not be economically feasible (filly-equipped dual-head stiffener welding tractors can be had for under $501& substantially less than the cost of one laser). However, if laser welding of ship structure became economically feasible, the concept of using a lower-powered beam for a precleaning function is inherently practical. Since this idea was not the three-edge mode upon which this study was focused, it was not investigated.

Work done to date[5] has concentrated on broad-area, single-surface removal coatings, so that the issues of cleaning a narrow strip covering multiple edges have not been considered. Further, the coatings removed have been thicker than those expected in the pre-weld cleaning scenario. Removal rates from 0.62-0.87 ft^2/min (576-808 cm^2/min) were observed at various laser operating parameters. At these rates, assuming the cleaning of l-inch (25.4mm) wide strips on each of the top and bottom surfaces, and a 1/2 inch (12.7 mm) face (approximately 2.5 in^2 [16.13 cm^2] per linear inch of edge), a weld edge could be cleaned at a rate from 35-50 ipm (0.8-1.3 mhnin.). For PCP'S the typically thinner coatings should allow a speed increase.

One recent study,[6] using an Nd:YAG laser with the beam delivered by fiber-optic cable, treated surfaces coated with 3 roils (0.075 mm) of lead-based paint. Only 5V0 of the coating weight remained after laser stripping this was an ash residue composed primarily of the paint solid pigmenting materials (compounds of iron, titanium lead and chrome). Organic compounds broke down into 89% water vapor and C02, and about 11% acetylene and ethers.

There has been little information generated about the breakdown products generated during hot work on inorganic zinc preconstruction primers, although some information has been published overseas[7] on the effects of heat on a limited number of protective coatings. Since most air sampling methodologies rely on choosing, before the test, specific elements and substances to measure, knowledge of the formulation of a coating may be critical in establishing a test plan which targets the specific substances expected to be captured. Thus for the testing of laser beam paint stripping, while sampling for metallic contaminants was peformed (details in Appendix B), testing for volatile products of combustion was considered to be beyond the scope of this project.

Testing on IZ-PCP was performed at Hobart Laser Products, Livemore, California, and at the Applied Research Laboratory (ARL) of Pennsylvania State University. Both sites used fiber-optic coupled Nd:YAG lasers of continuous 2.4 kW peak power, but lower power levels were adequate to break down I.Z coatings on 8x10# I/T specimens. Power levels and travel speeds were varied, from extremes in which the metal surface was melted, to those in which the coating was barely affected. A noticeable odor was given off as the primer was consumed. Noise level measurements were not made, since, unlike the other methods surveyd, the laser devices were inherently silent. Where oxygen or air at higher pressures might be used to speed up the process, noise from this source could become a factor.

The laser end effecter at ARL was transported by a simple commercially available geared-track tractor, with a device to oscillate the beam across the direction of travel. The part was positioned at a 45-degree angle, and the ability of the beam to break down the paint at the extremes of focus was evaluated. A band approximately l-inch (25.4mm) wide was easily produced. Figure 14(a) shows a test piece which has just been treated. The red stripe at the end is made by a very low power Helium-Neon aiming laser, and shows the oscillation pattern across the faying edge and one surface. Figure 14(b) shows a test piece with coating removal at 2.4 kW laser power, and different travel speeds. As a comparison, the tag denoting “G” and “WB” is positioned between two areas which have been cleaned by grinding and wire brushing, respectively. At low travel speeds, melting of the base metal has occurred. At Hobart Laser Products, two test plates were cleaned of IZ PCP. In one sequence, shown in Figure 15, travel speed was held constant at 90 inches per minute (2.3m/min.), and beam power levels were varied. In Figure 16, power has been held constant at 1350 watts, and travel speed was varied.

Residues left on the plates were easily removed by wire brushing, but some areas were left as-is to be subjected to Energy Dispersive X-Ray (EDAX) analysis in a scanning electron microscope. EDAX analysis showed that zinc residues from laser stripping were lower in zinc content (7.5°/0) than those remaining from grit blasting (17.70/0). These results are described in greater detail in Section VIII of this report.

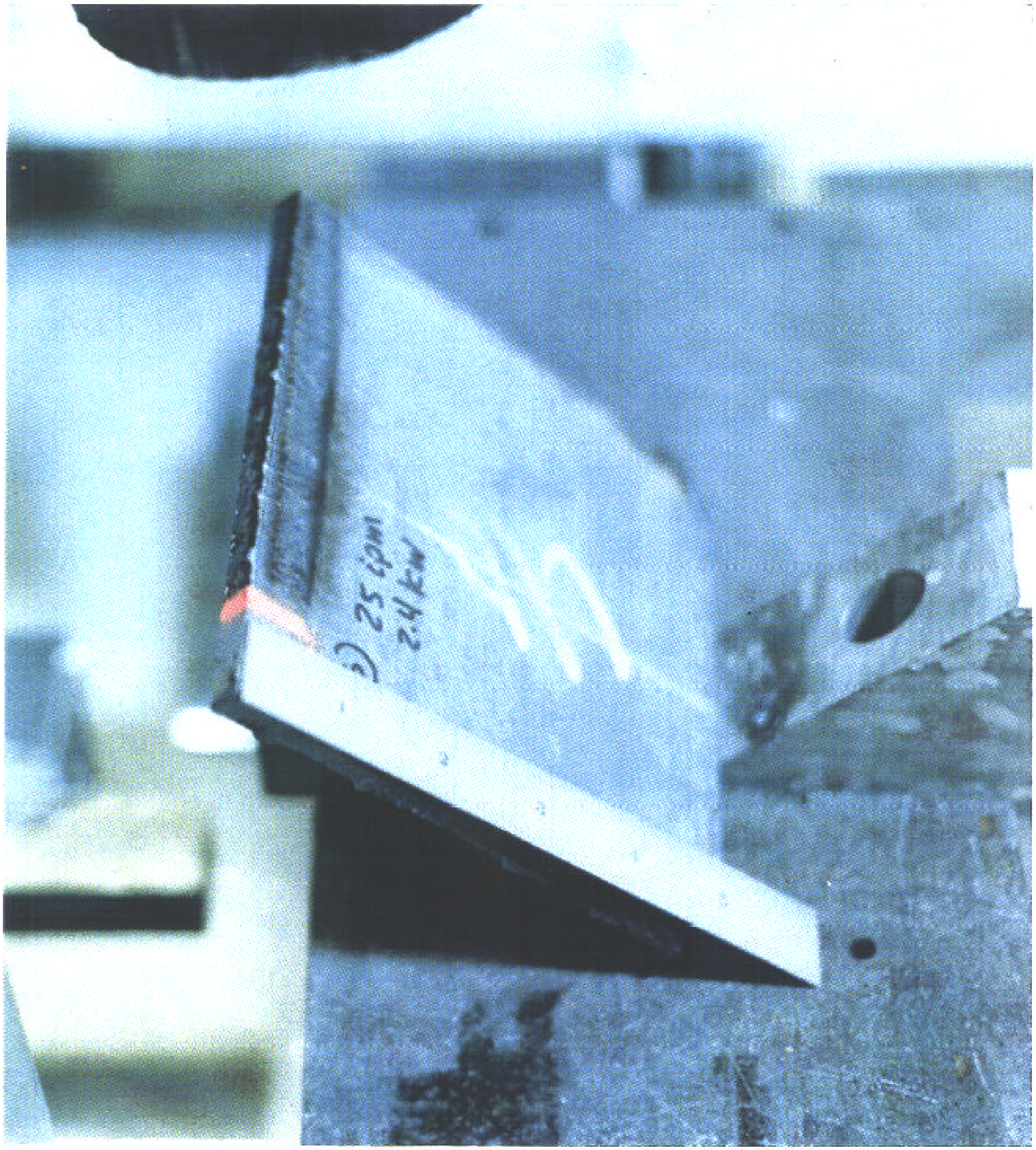


Figure 14(a). Laser paint stripping at ARL/PennState. Two edges cleaned simultaneously at 25 ipm (0.6m/min) achieved by oscillating beam. Red stripe of Helium-Neon laser indicates the oscillation pattern, and is used for "aiming" the Nd:YAG beam.

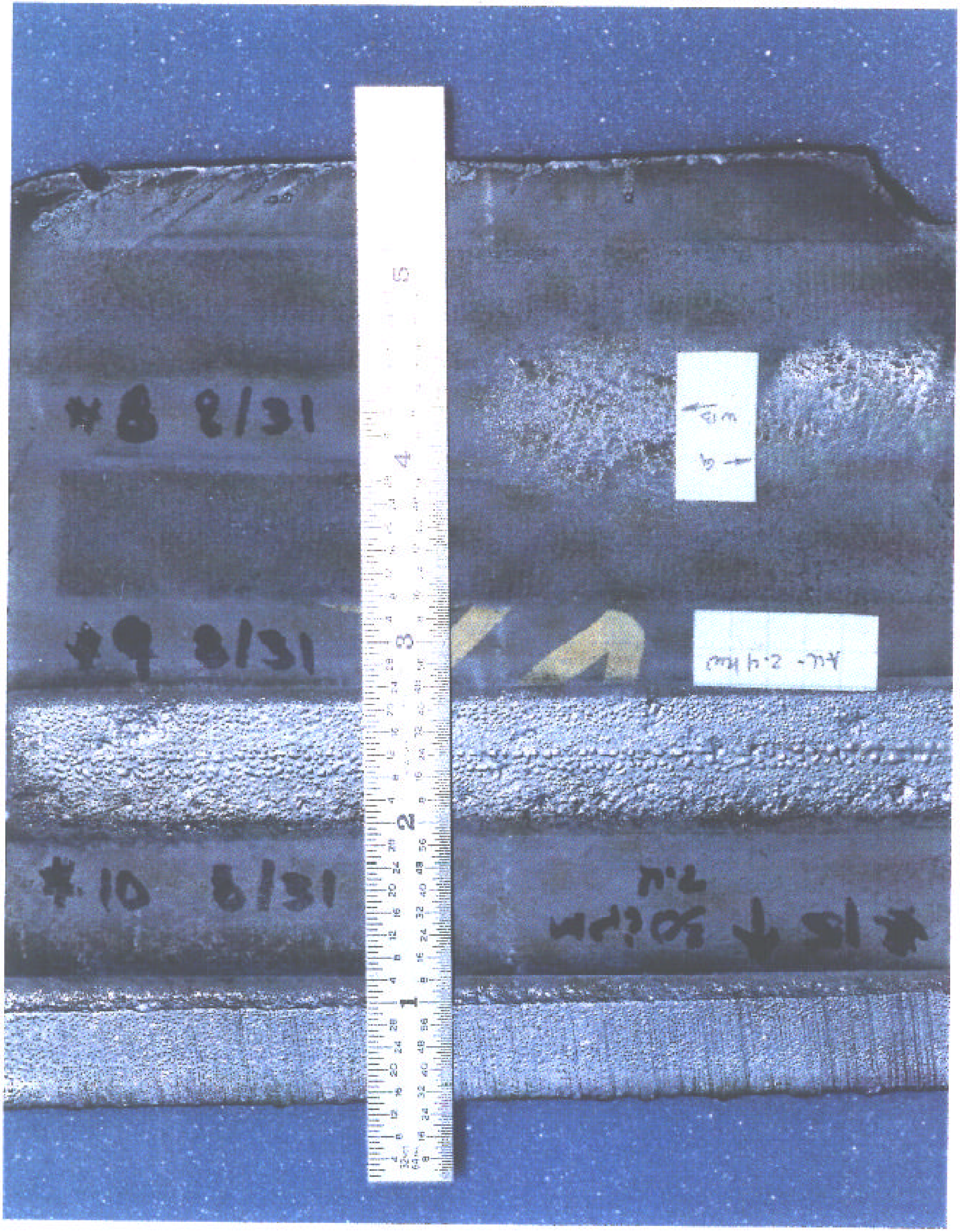


Figure 14(b). Laser paint stripping at ARL/PSU. 2.4 kW at various speeds. "G" and "WB" indicate comparison areas cleaned by grinding and wire brushing.

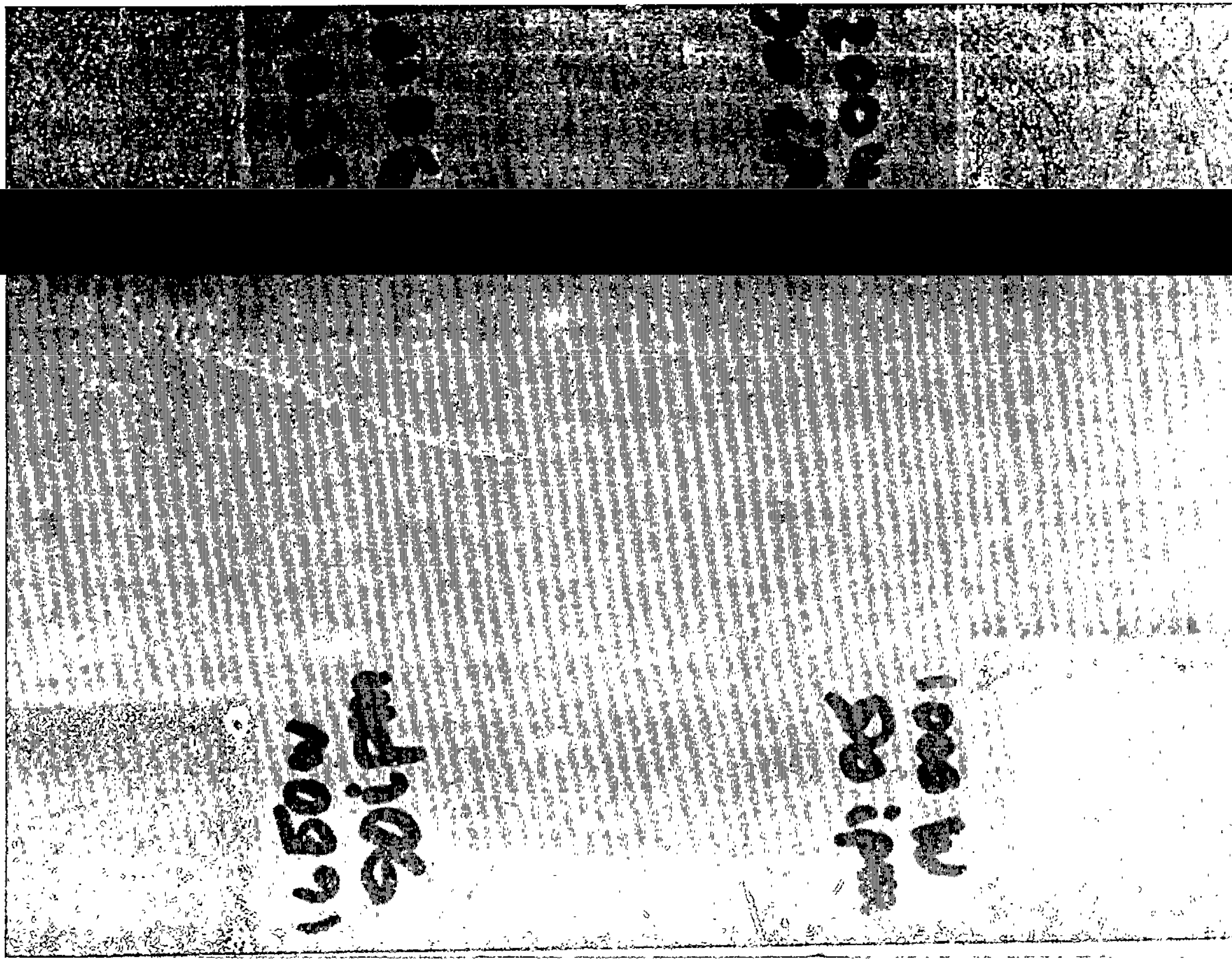


Figure 15. Laser paint stripping I/Z primer, 90 ipm (2.3m/min), various power settings .

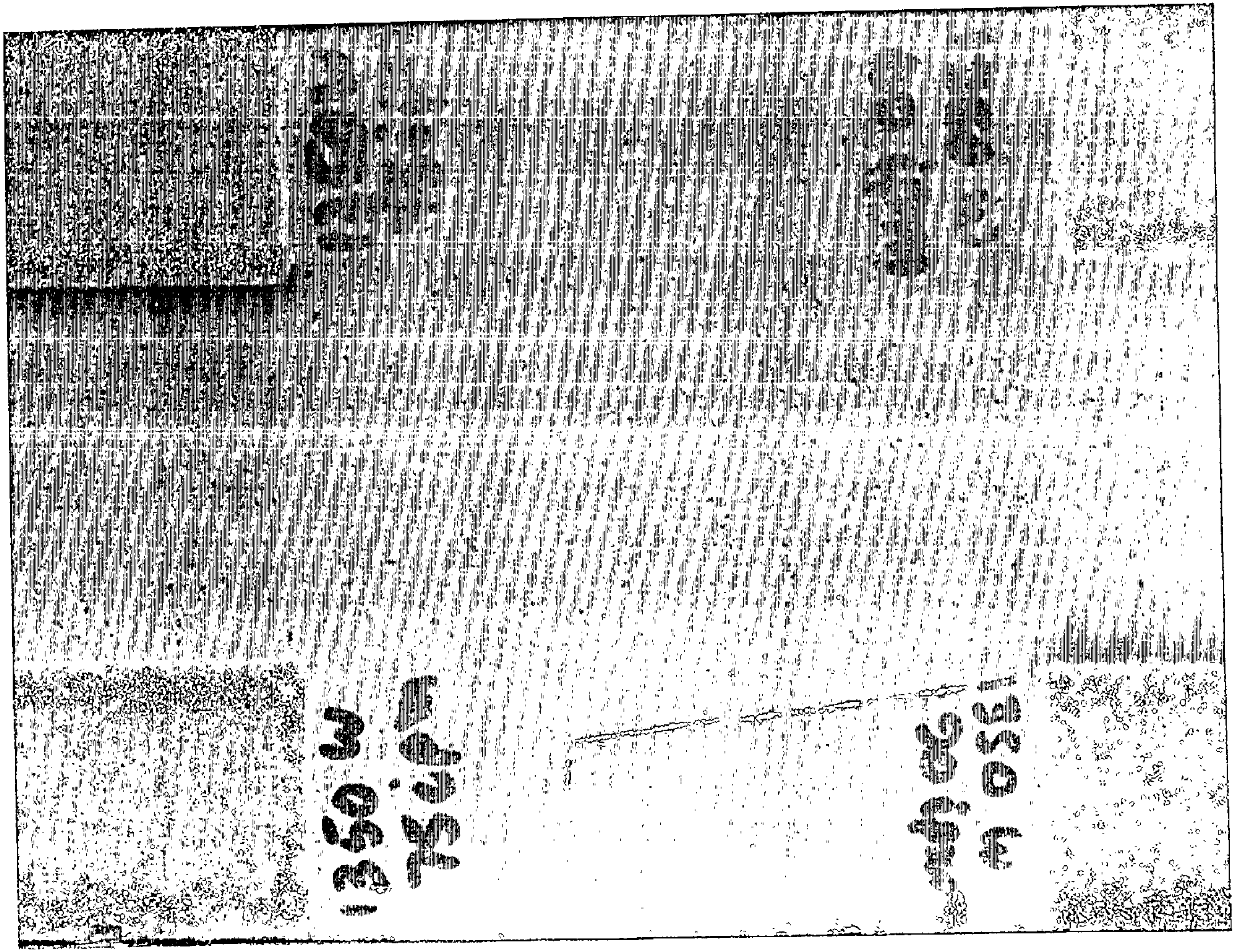


Figure 16. Laser paint stripping I/Z primer, 1.35 kW, various speeds .

Vacuum Shrouded Needle-Gunning

Equipment of this type was surveyed at the manufacturing operations of Pen-Tek, Inc. in Coraopolis, Pennsylvania. A typical needle descaler is encased within a movable plastic enclosing shroud, which can be held against the work piece as the coating is being removed. Shrouds are currently available for flat surface operation and for work on outside and inside corners (two-surface cleaning). Vacuum on the shroud picks up the debris and a cyclone filtering system drops it into a drum for disposal. The manufacturer claims that the system has been used on lead abatement and other contaminant removal projects, with excellent results. Most of these projects have required cleaning of large areas of flat surfaces.

A brief test was peformed using an 8x10# I/T coated with IZ. The needle configuration had difficulty with the comers of the intersecting edges, and overall, the operation was relatively slow compared to grinding. Capture of removed coating appeared to be excellent. Noise measurements were made, and are quantified in Appendix B. Subjectively, noise appeared to be more of a problem due to the nature of the I/T to act as a sounding board. Figure 17, courtesy of Pen-Telq shows the device being used on flat surfaces and corners.

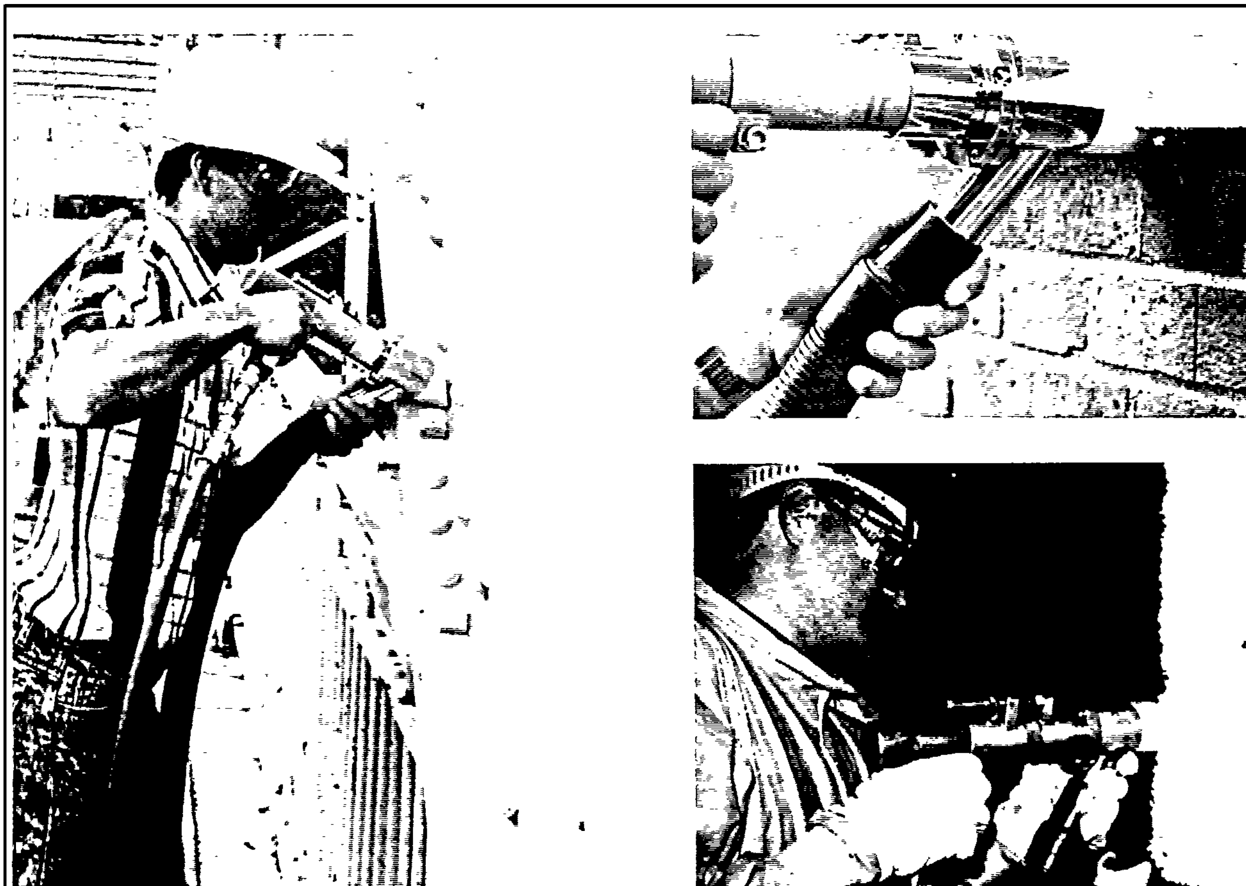


Figure 17. Vacuum shrouded needle gun, with shrouds for flat surfaces, inside and outside corners. (Photos courtesy PenTek, Inc.)

High Pressure Water Blasting

Water blasting has come into prominence because it does not release airborne hazardous dusts. This technology began to grow in the1970's in relation to the increasing disfavor with open-nozzle grit blasting shown by environmental regulatory authorities, particularly in the area of building restoration and maintenance. Water, typically at 35,000 psi (241 mPa) is delivered to a nozzle at a rate of up to 10 gpm (38 I/tin), although other pressures and flow rates may be used. The momentum and kinetic energy of the water mist is sufficient to dislodge coatings such as paint, grease, dirt and rust without significantly affecting the substrate. Compared to grit blasting, water blasting has an advantage in being able to remove wet or viscous contaminants such as oil and grease. There have been undocumented claims that the kinetic energy transferred to the metal substrates causes sufficient heating to dry any residual water. This remained to be established experimentally, since the method has not been used for pre-weld cleaning, and moisture has an adverse affect on welds, especially with hydrogen-sensitive materials. Obviously, ambient conditions can affect the ultimate dryness of the finished product.

The technology is amenable to vacuum recovery of liquid, mist, and particulate, although specialized vacuum systems may be required to handle liquids mixed with solids. A definite advantage of vacuum recovery is that the air movement will aid in drying plate surfaces. Design of a system for three-surface cleaning should pose no special challenges beyond the shrouding of the heads for containment of debris and personnel protection, as well as the cost issues associated with the initial design of any piece of equipment. This method has not been tested in any applications for pre-weld cleaning; thus, any published removal rates are base on treatment of fairly thick paint films.

Water-blast units cost about $90K, for the blast unit only. Custom-designed nozzles and vacuum recovery systems will add to the cost. Water must be filtered, to avoid clogging or damaging the system. Electrically powered or engine-driven pumps maybe used, and energy consumption is not a significant factor. Certainly, care in the disposal of the runoff of water and removed paint must be taken. Disposal costs maybe reduced by filtering the water to remove contaminants, but such equipment will add to the first cost of the system, and the degree of purity to which water must be treated may vary with local regulations.

National Liquid Blasters (NLB), of Michigan, provided equipment shown in Figure 18 for a basic evaluation. An 8X10# I/T shape coated with 0.8 mil (0.02mm) of IZ-PCP (see Figure 19) was cleaned by a blast head manipulated by a Cincinnati Milacron (hydraulic) robot arm moving at rates of 12-25 fpm. (3.8-7.6 m.min). Of particular interest was the opportunity to see if in fact the kinetic energy of the water stream would cause sufficient heating in the workpiece to evaporate residual water off the part in some measurable amount of time. During cleaning, the test piece was shrouded in a cloud of mist (see Figure 20). Paint removal was excellent, and although slightly warm to the touch, the residual surfaces were still quite wet tier cleaning, and remained wet (see Figure 21) for many minutes. Drying occurred slowly where water had run off, but areas where water had puddled did not dry quickly, and took long enough that measuring drying time was not worthwhile. Formal noise level measurements were not made, but previous experience suggests that 95-100 dBA exposure is typical.

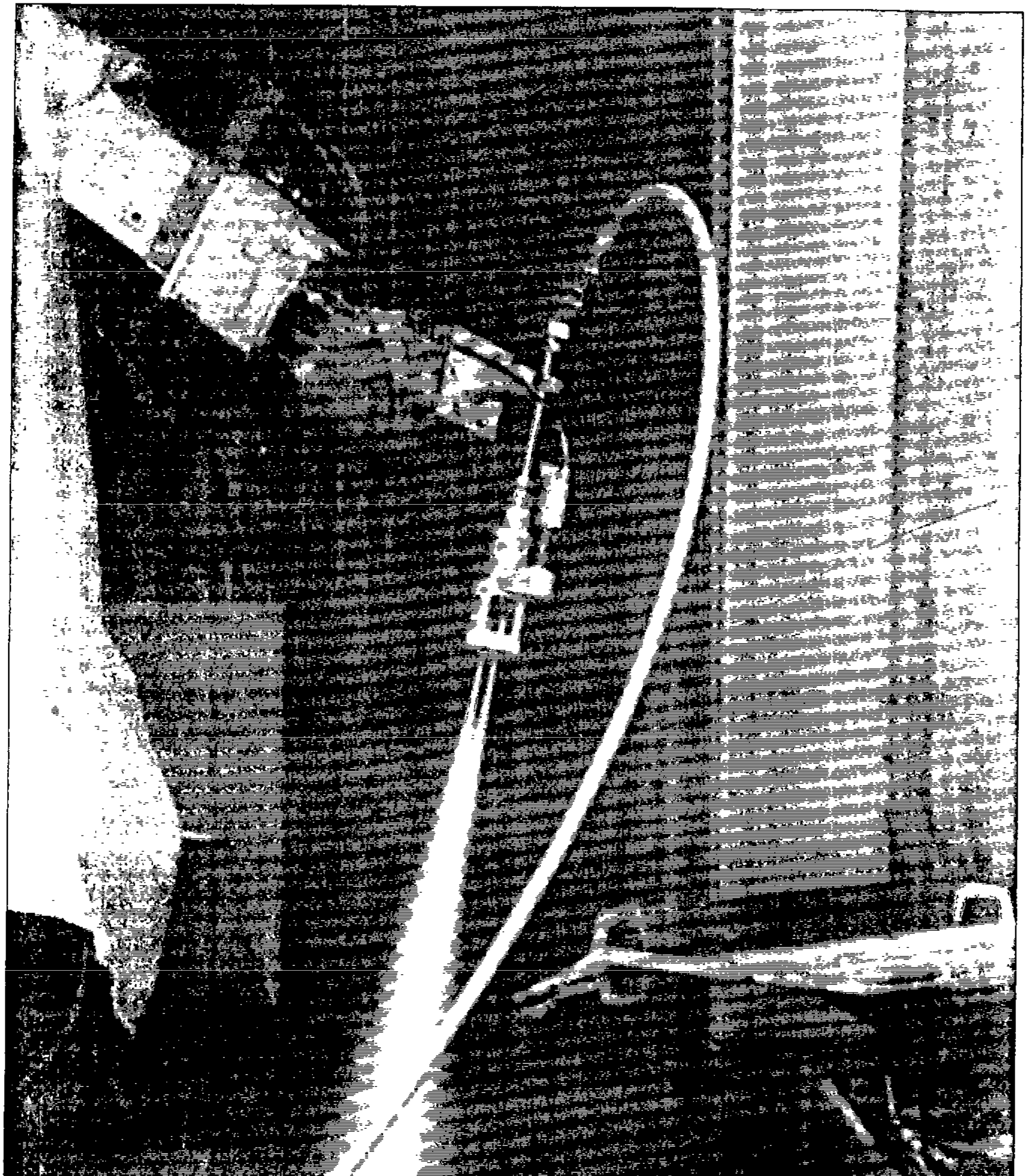


Figure 18. Water blast head mounted on robot arm. This head has two nozzles which rotate during operation to provide wider coverage.

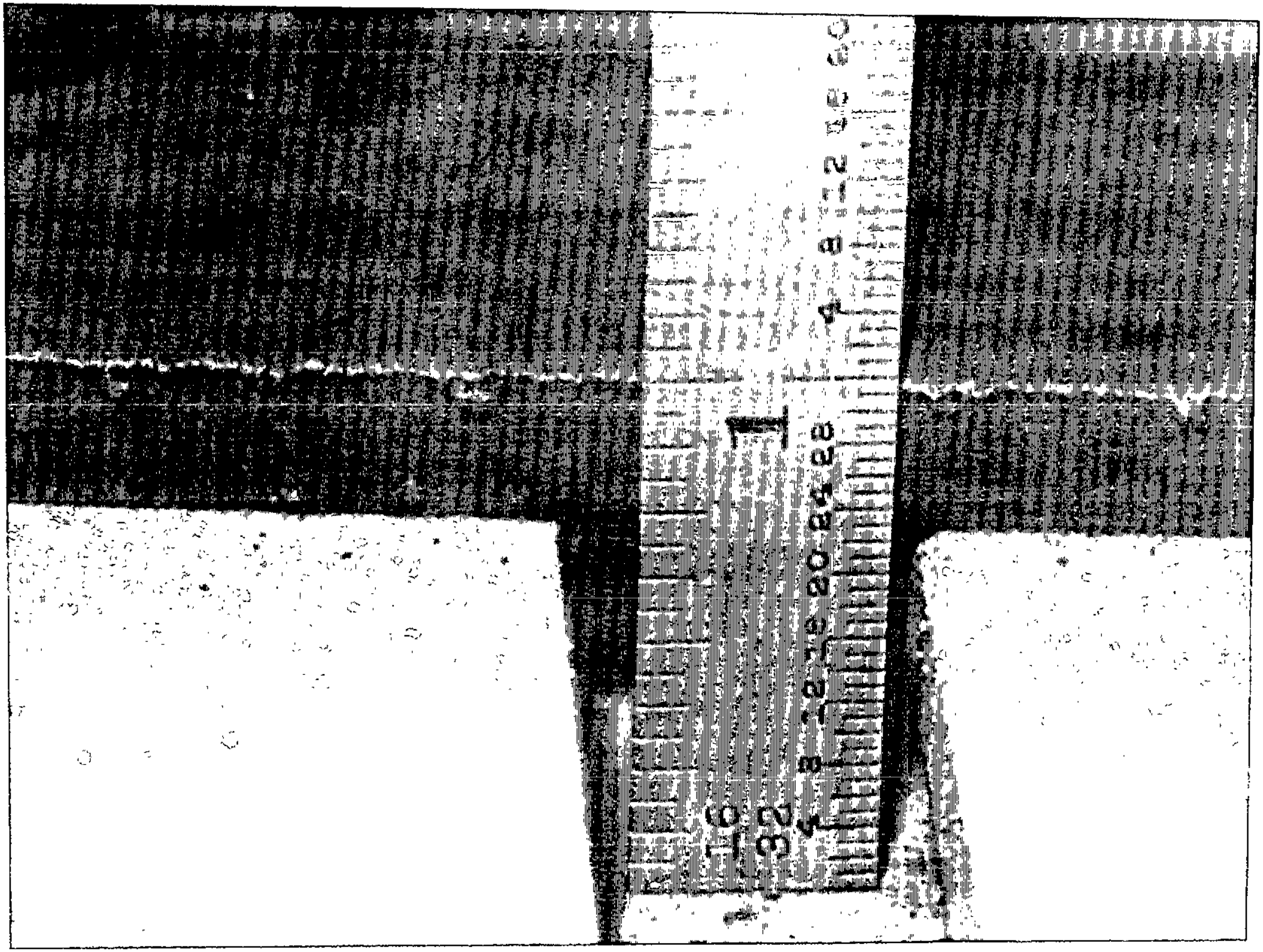


Figure 19. Edge of I/T primed with I/Z prior to water blasting.

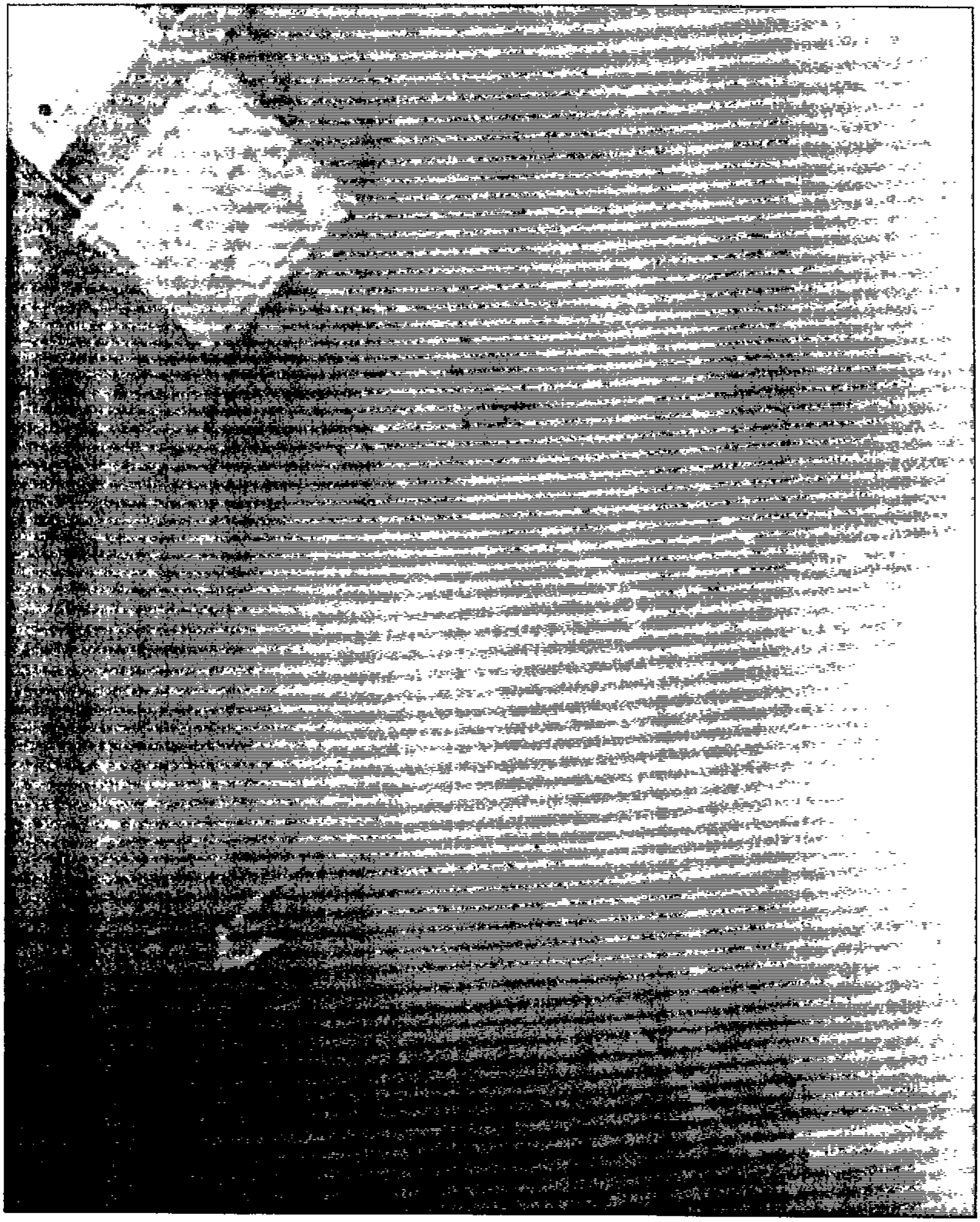


Figure 20. Water blasting of I/T in progress, substantial vapor mist is apparent.

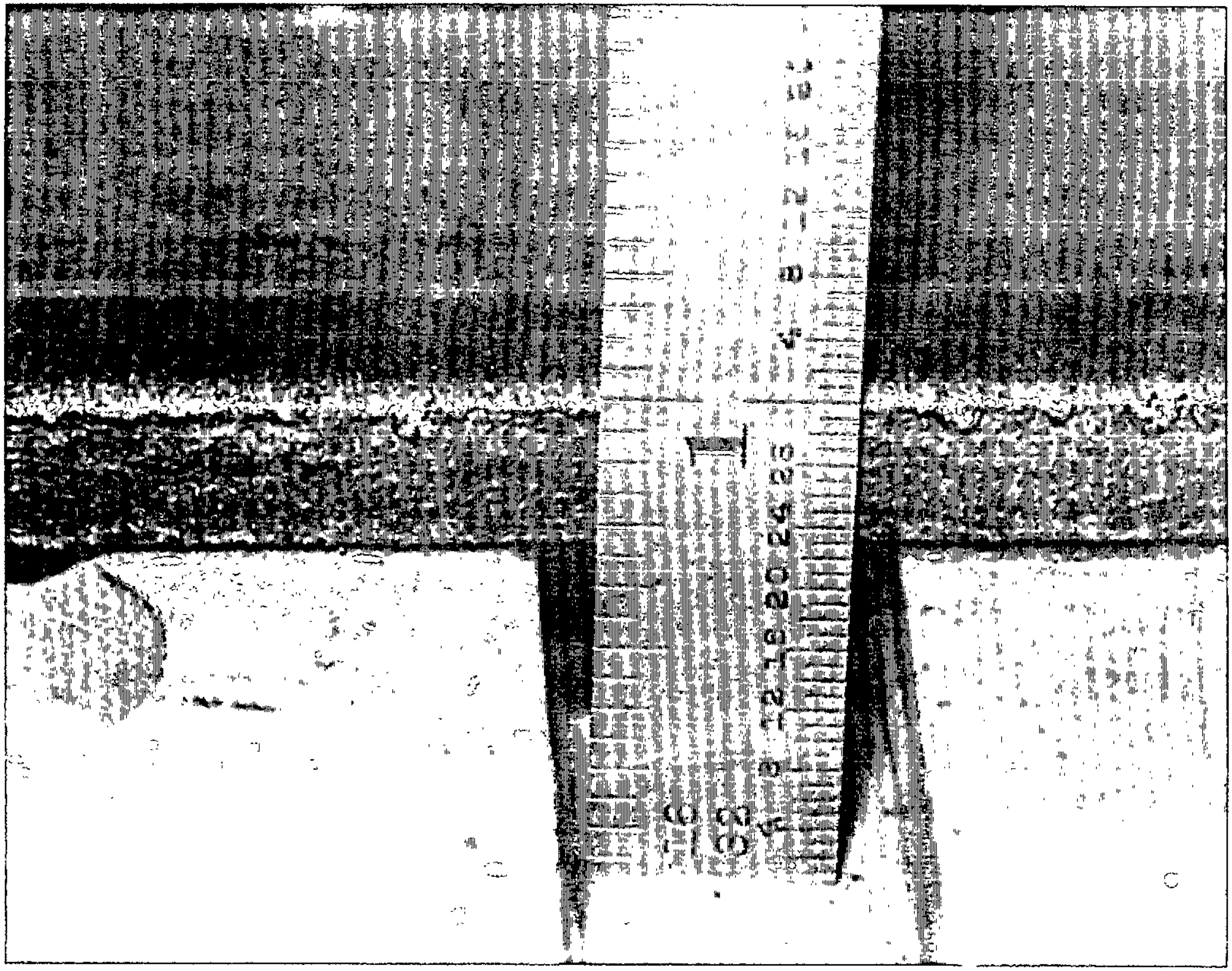


Figure 21. Edges of I/T after water blasting .

Carbon Dioxide Bead Blasting

This ,method uses dry ice (solid C02)pellets as the blast medium. Compared to grit blasting, one significant advantage is that greasy or oily surfaces pose no problem. Another advantage is that after blasting, the pellets sublimate to gas leaving only the surface material removed instead of a large quantity of grit contaminated by a smaller quantity of coating fragments. Thus disposal costs can be substantially lower, especially when hazardous coatings such as lead are removed. A further claim of C02 bead blasting is that the substrate is unharmed by the blasting process, and that only the coating is removed. This fact is used to advantage in the cleaning of some molding dies, where dimensional integrity is essential, and in the cleaning of coatings from circuit boards.

There is a current project to add a vacuum shroud to a C02 blast gun for flat-surface cleaning, but as of this writing, prototype testing had not begun. There has been no work on simultaneous cleaning of multiple edges. A significant concern is the potential for concentrations of C02 gas which can displace oxygen in confined spaces, so consideration of workplace ventilation is a paramount necessity.

Cryogenesis, of Cleveland, Ohio, provided equipment for this test, shown in Figure 19. Fabricated entirely of stainless steel, the equipment shown in the picture costs approximately $28,000.00. A reservoir is filled with pellets, and operating parameters are set on the control console. As shown in Figure 20, the gun is a simple, rugged affair with a “dead-man” type trigger unit located on the handle.

Carbon dioxide beads are extruded from compressed liquefied C02 in a pelletizer that costs $39,000. In addition to manufacturing the blasting and extruding equipment, Cxyogenesis also produces C02 pellets for sale to support operations for which the cost of ownership of extrusion equipment is not economically justified. The beads can be stored in insulated containers which allow shipment over long distances without significant loss of material. Such a storage container is shown on the left in Figure 22. The pellets used for this test are shown in Figure 24; different dies are available for the pelletizer, allowing pellets of different cross-section to be made.

A short section of 8x10# I/T with a coating of IZ-PCP, and two pieces of 4x4x3/16 Tee coated with a water based epoxy PCP were cleaned. To get an idea of the delivery pressures necessary, testing was first done on areas of flat surface. When it was felt that the best pressure was achieved, two edges were cleaned simultaneously by directing the gun at the comer of the web top surface and the faying edge, as shown in Figures 25 and 26. The coatings were removed, except for some residual material at the radius of the flange stub of the I/T (see Figure 27), and remnants of the primer were seen to adhere (Figure 28) in the deformed area of the shear lip of the 4x4 Tee. The process was extremely loud, especially on the epoxy PCP. It was noted that while delivery pressures of 80 psi (0.55 mPa) were sufficient to remove the IZ (causing noise levels of up to 108 dBA) at a rate of approximately 38 ipm (0.95 m.min.), pressure had to be boosted to 195 psi (1.34 mpa) to adequately remove the epoxy coating, resulting in higher noise levels (up to 130 dBA). Even at that pressure, the speed of coating removal was less than 10 ipm (0.25 m/min). Appendix B contains greater detail of this evaluation.

Figure 22. CO2 pellet blasting equipment.

Figure 23. **CO2 pellet blasting gun.**

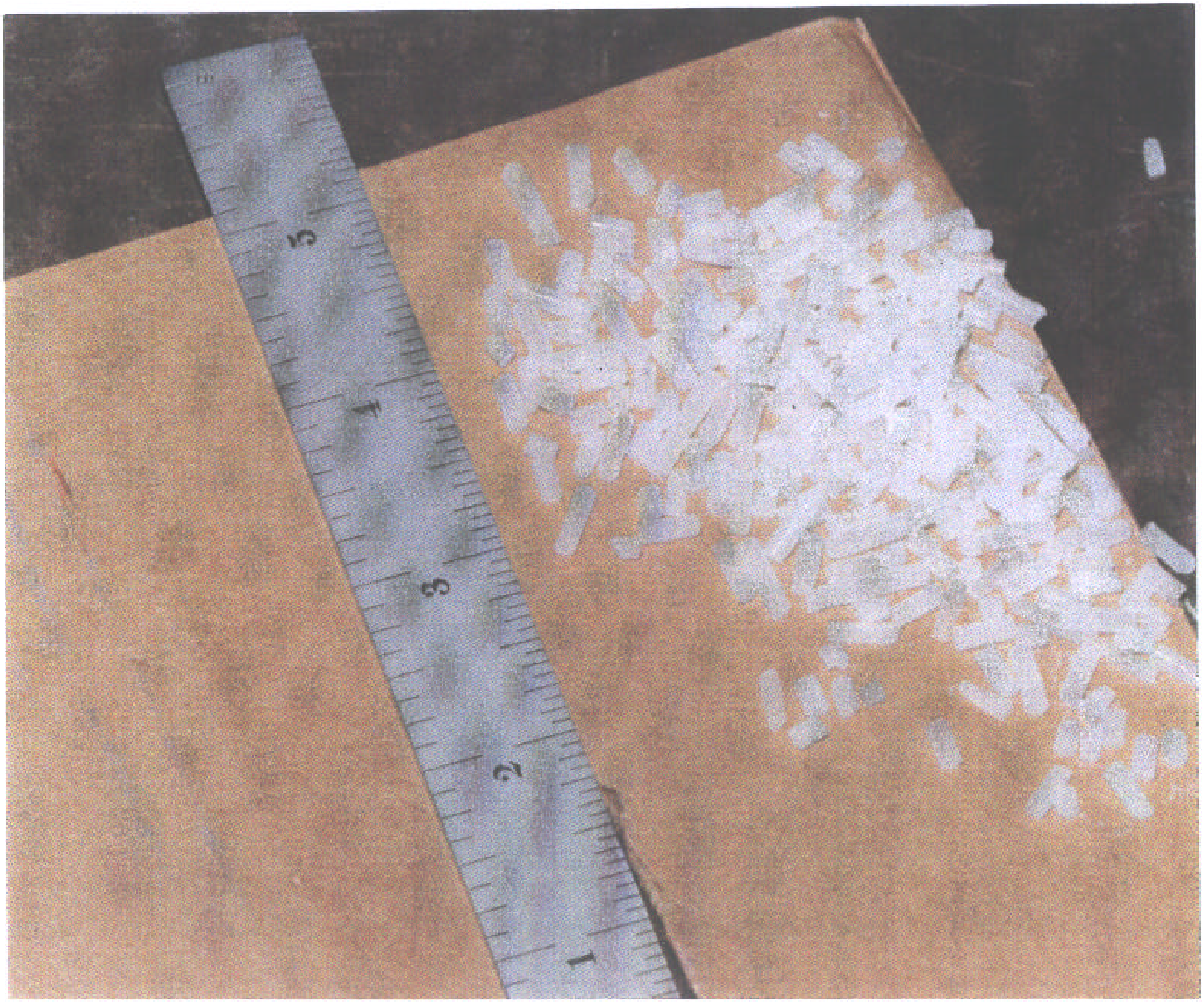


Figure 24. CO2 pellets.

Figure 25. CO_2 pellet blasting two edges of I/T primed with inorganic zinc.

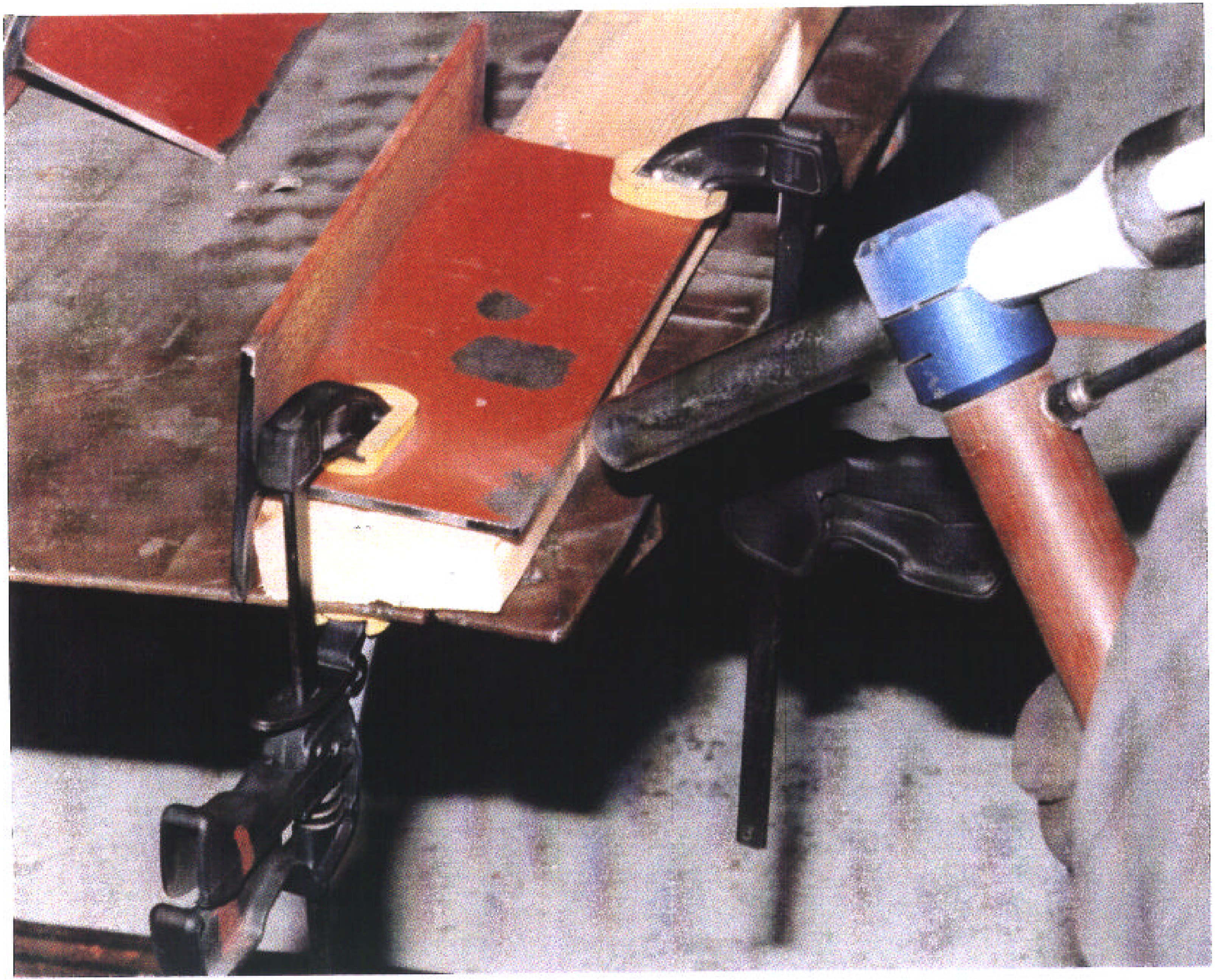


Figure 26. CO2 pellet blasting two edges of Tee primed with epoxy PCP.

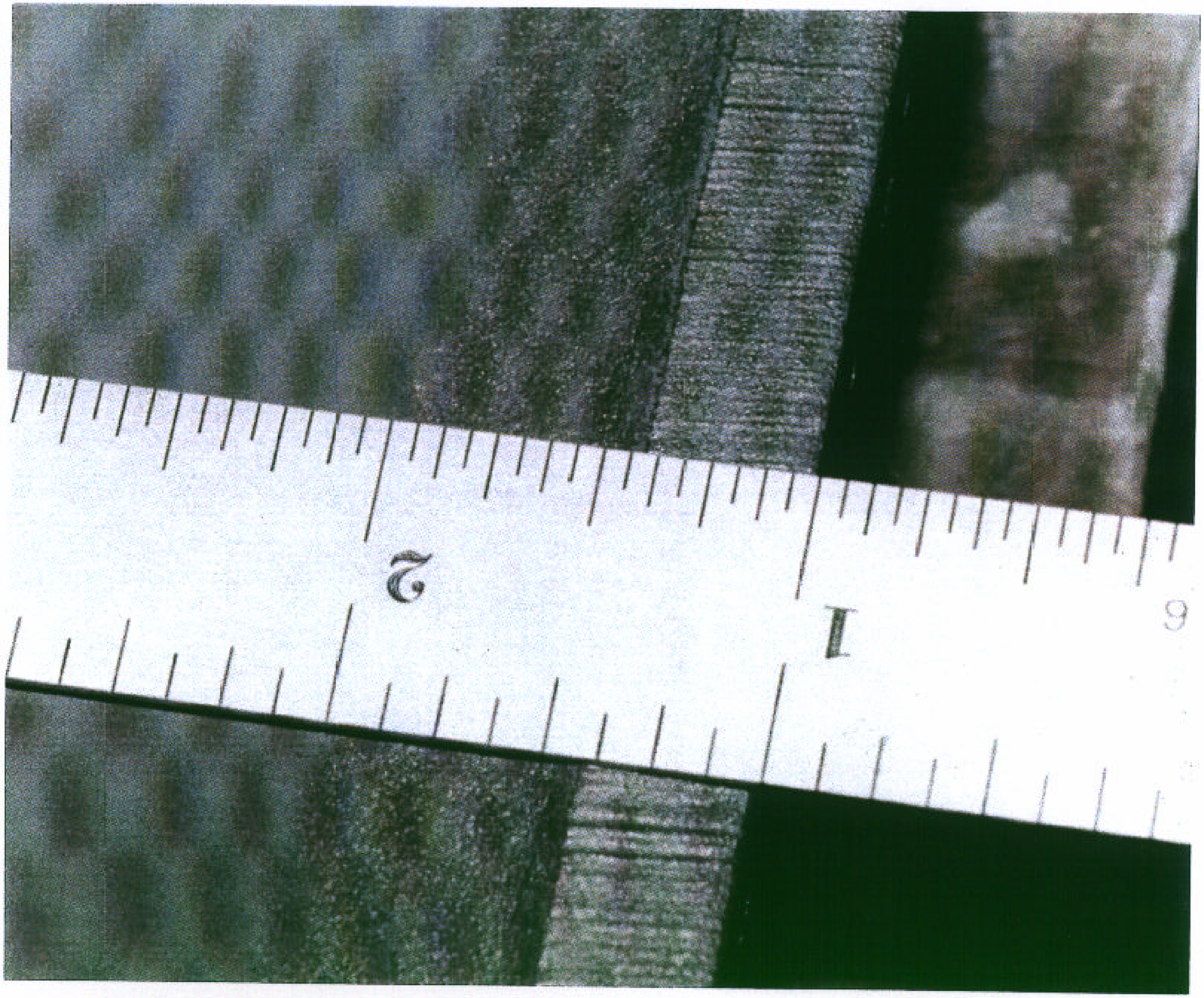


Figure 27. I/T after CO2 pellet blasting . Note residual primer at radius.

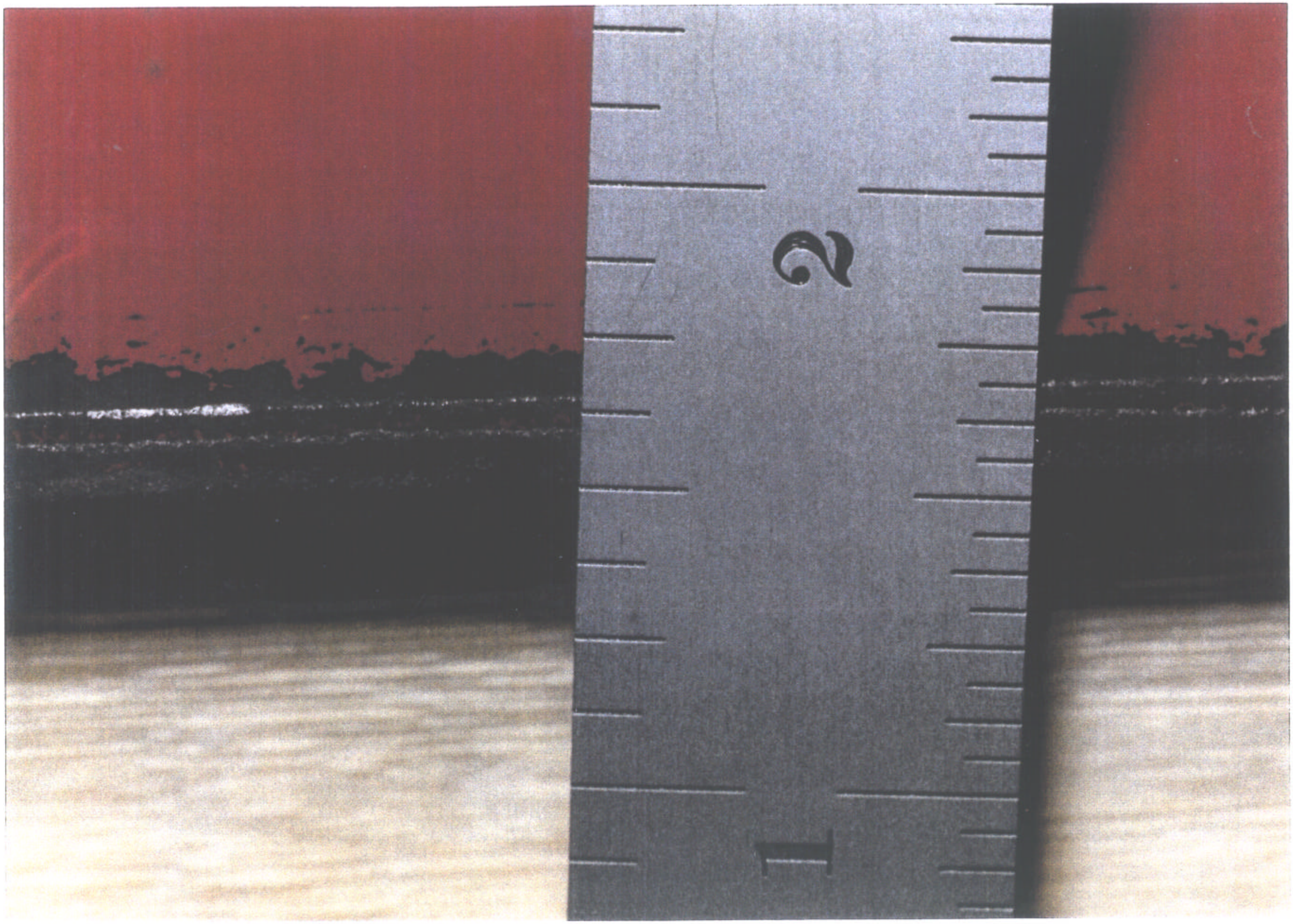


Figure 28. Tee primed with epoxy PCP after CO_2 pellet blasting. Note residual primer at edge.

High Velocity Oxy-Fuel (HVOF) stripping

More familiar as a metal-spraying application, this method has not been used for base metal weld edge preparation as yet. It has been used for paint removal in some innovative situations, such as the stripping of highway lane marking paint from roads without damaging pavement, and has seen application in granite finishing, in which the high temperature gradient causes surface irregularities on the stone to span off, leaving a coarse but very uniform surface. The technique very quickly removes the surface markings of wire saws and renders a marketable product at low added cost.

The method relies on a specially designed water-cooled chamber in which all combustion takes place, as opposed to ordinary flame torches for which gases burn outside of the tip. Combustion products leave the nozzle at hypersonic speed and very high temperatures. Both kinetic energy and temperature plausibly allow the transfer of sufficient energy quickly enough to disintegrate a coating with minimal affect on the substrate. The torch design is simple and rugged, easy to use and maintain, and has a relatively low initial cost. Of reasonable concern is that with low actual heat input to base metal, water of combustion may condense on plate surfaces. On the other hand, if heat transfer rate is high and travel speeds sufficient, the surface may become just warm enough to prevent condensation without becoming hot enough to cause thermal damage. Also, gases may retain enough heat to keep moisture in the vapor state.

Individual HVOF torch assemblies cost less than three thousand dollars, and use ordinary fiel gases and oxygen. Custom configuration to produce a device capable of three-surface cleaning would require a minimum of two torches, sufficient water cooling capacity, and shrouding for operator protection. Vacuum for time removal has not been used so far, so that the issue of materials capable of withstanding the temperatures involved needs to be assessed, and could be a significant part of the cost. Fuel gas and oxygen are the principle consumables, with cooling water being a consideration. Water coolers are a few hundred dollars, or as in the case of the quarries, water can be run through and drained off. Typically, chillers have not been necessary, so that electrical power should not be considered a consumable. There is no experience available to support a good estimate of the speed of cleaning of preconstruction primers in a mode of multiple-edge removal.

Hanson Machine Company, located in Boscawe~ New Hampshire, provided an HVOF torch for testing, shown in Figure 29. In use, the flame was nearly invisible (see Figure 30), and, being a hand-held torch it was relatively easy to overheat the material. When travel speed slowed, the area under the flame quickly became red-hot. This would be a concern for heat-sensitive materials. The IZ coating was seen to discolor slightly, leaving a light brown residue, indicating that breakdown of the primer had occurred. There was no evidence of water of combustion condensing on the plate surface. Due to the high velocity of expanding gases, the device was inherently loud, and noise levels of nearly 95 dBA (details in Appendix B) were recorded. No testing for airborne contaminants was peformed. In general, the same arguments regarding thermal breakdown products[7] of coatings would apply to the method as to laser beam stripping.

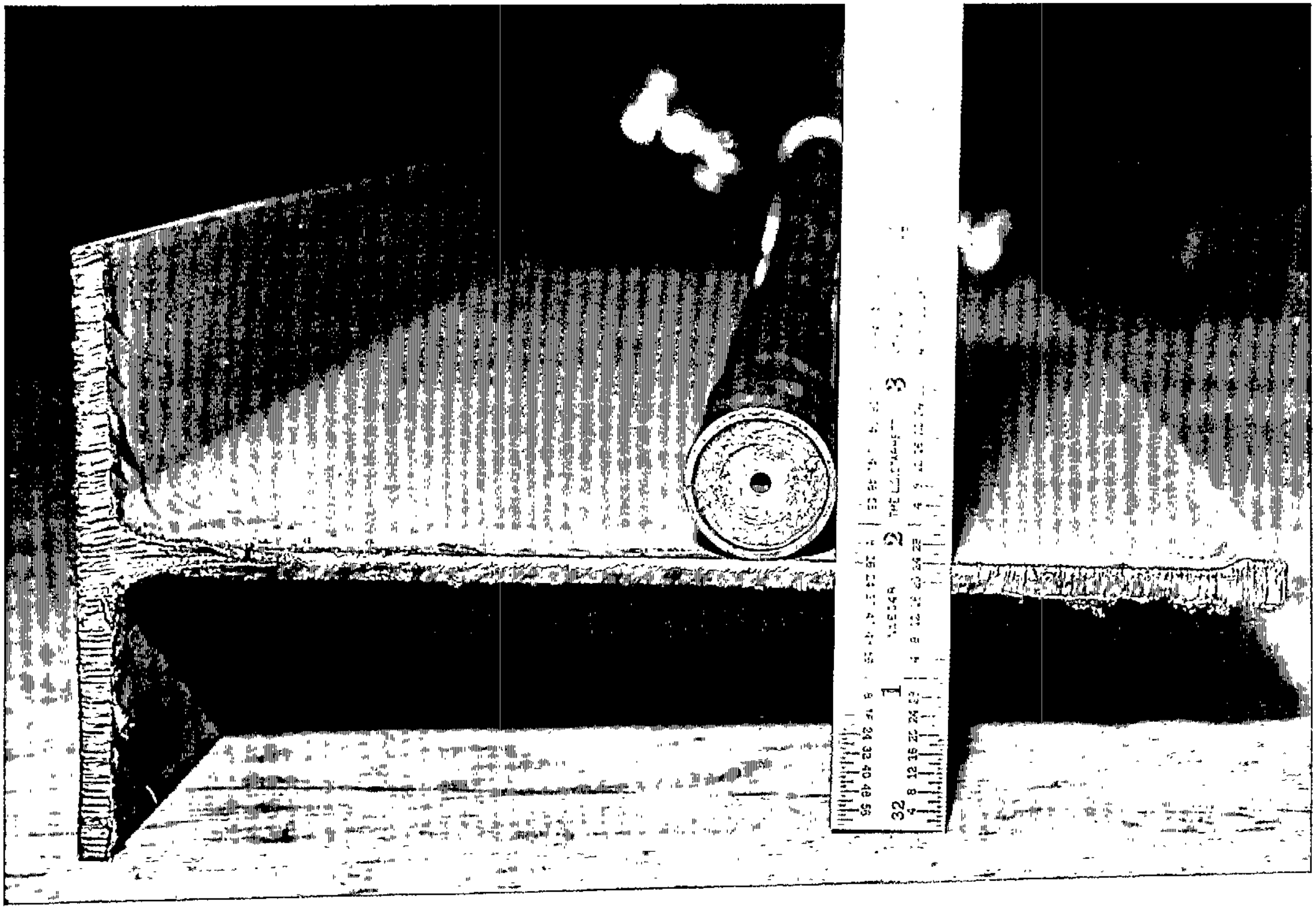


Figure 29. HVOF stripping torch on I/T test piece .

Figure 30. HVOF stripping in progress on I/T test piece.

VL SHIPYARD TRIALS OF VACU-BLAST SYSTEM

Site trials of the "Super Utility Vacu-Blaster" at Kelco, performed with a 30-foot (9m) hose harness assembly showed positive results. This machine was the only unit available for rental, and was therefore selected for use in the shipyard trial at Bath Iron Works. The Vacu-Blast machine was re-equipped with sufficient hoses to allow work on 50-foot (15.3m) plates, and was supplied with the newer-style three-edge gun. A few modifications had been made to the unit based on experience in the vendor site trials of the machine. These consisted of changes to length and configuration of hoses near the guw a different "dead-man control valve," and some grinding to smooth out sharp edges on the vacuum housing of the gun unit.

For all shipyard tests, type "G-50" steel grit was used. In addition to the three-edge gun two different single-sutiace guns were evaluated. To assure that the devices were being used properly, Mr. John George was hired to assist in the training, operation and evaluation of the system. Mr. George, with many years' experience in the field of abrasive surface treatment (particularly in the use of vacuum recovexy/recirculation systems), provided invaluable service to this project. Photographs of the shipyard trials are limited to those situations which are unique, and not repetitive of earlier illustrations.

Test Cycle

The purpose of the yard trial was to establish the overall suitability of this device in a production setting. Since the safety and environmental issues had been established in the vendor site trials, the major focus of the shipyard evaluation was in acceptability of the system to shipyard production personnel, effects of scale, such as use on longer plates and with longer hoses, particularly on vacuum recovery, and other environmental issues such as waste product disposal.

In addition to the weld joint pre-cleaning tests planned, the machine was also evaluated for the large-scale removal of primer from flat surfaces to an extent greater than that dictated by welding code requirements. Certain OSHA standards mandate that in some construction areas, specific coatings be removed within 4 inches (100mm) of a weld zone. This evaluation was accomplished using two different flat-surface cleaning guns. A final series of tests was run using a small flat-surilace cleaning gun to remove oxides tlom weld joints which had been fit but had rusted prior to starting the weld. Since joints of this type had root openings for the use of ceramic backings, particular attention was given to methods of sealing off the gap so that the blast media would not be a hazard to personnel working in the area of the opposite side of the joint.

Preparation for Testing:

Machinery was received at BIW during the week of June 12, 1995. After veri&ing that no damage had occurred in transit, the machine was setup on Tuesday, June 20. A review of the equipment by the BIW Ergonomics department confirmed the advisability of adding a shoulder strap. This was fabricated from nylon webbing by the BIW rigging loft. As much as possible, remaining sharp edges on the head were temporarily padded with masking tape. Figures31 and 32 show some of these modifications.

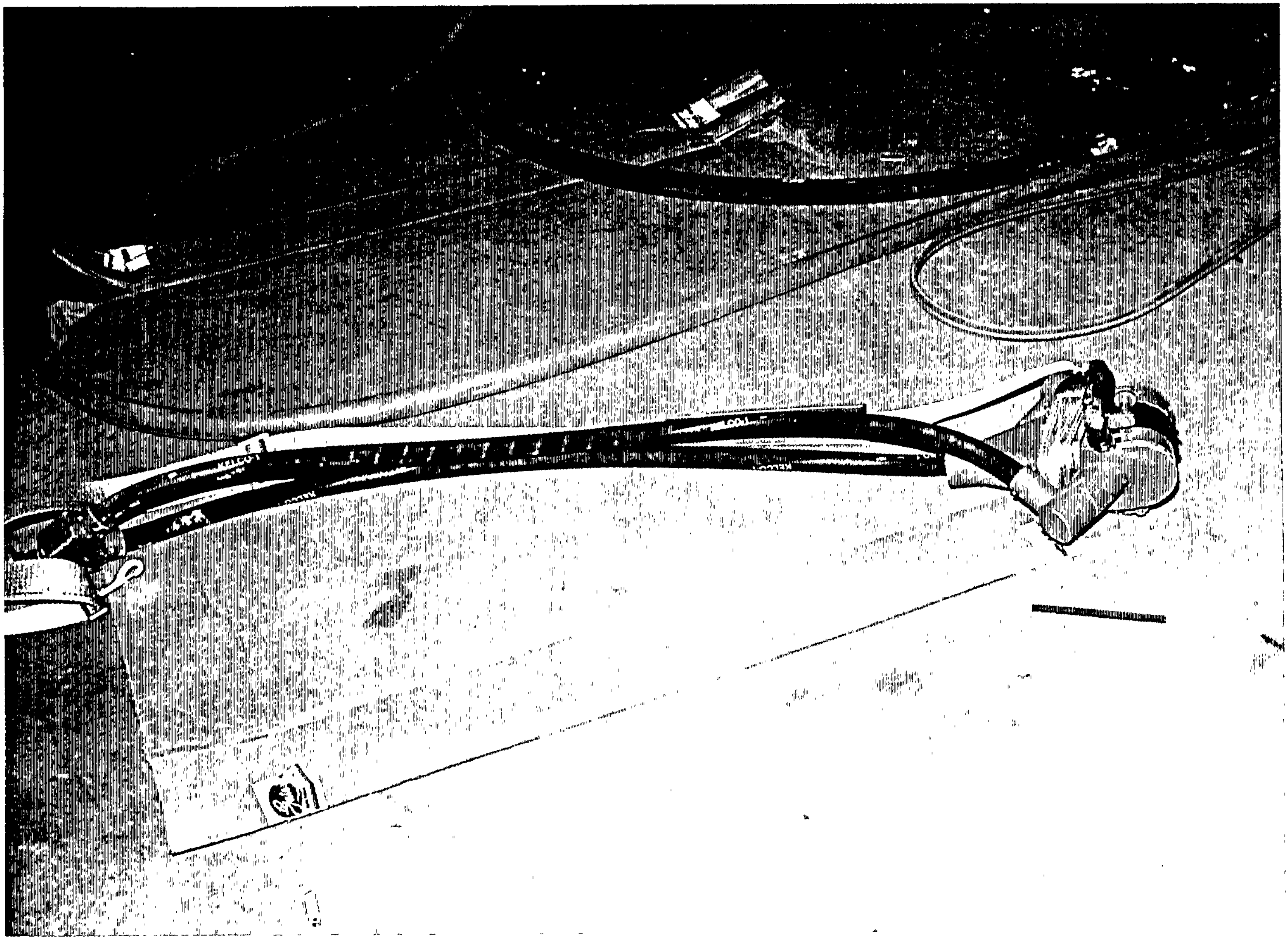


Figure 31. Modified three-edge blasting head (strap, padding, hoses, except vacuum hose not attached)

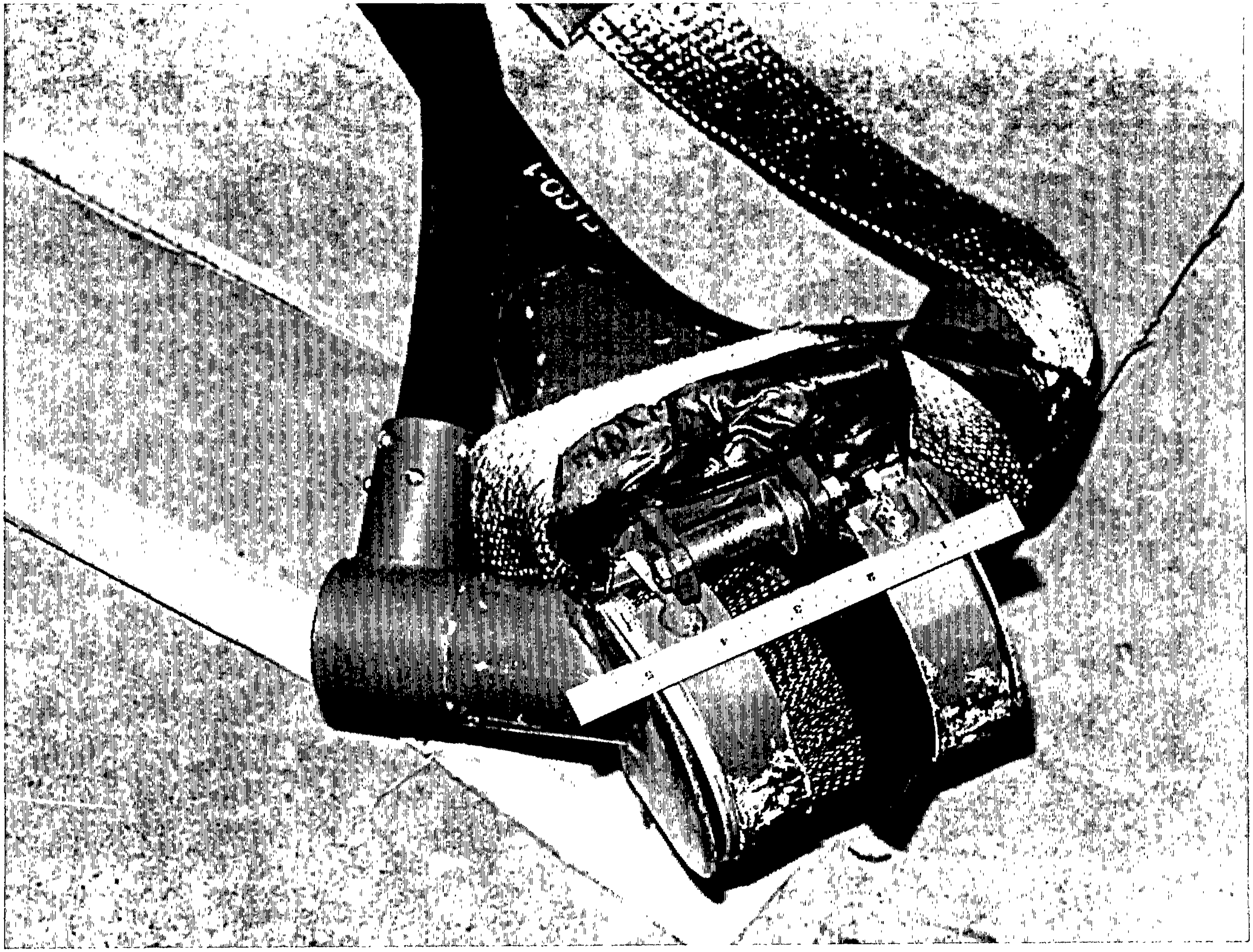


Figure 32. Three-edge blasting head (note strap and padding).

Initial set-up and testing showed that blast grit would “spill” out from the seal brushes, piling upon the plate top surface or falling to the floor from the bottom. Spillage was not a hazard, since high-velocity grit particles were well-contained by the seal brushes, but rather indicated that more grit was being supplied to the head than the vacuum system could recover. The quantity of material spilled reduced the available grit for blasting, requiring that the machine would have to be shut down more frequently for reloading. If spilled material became contaminated, it could represent a significant loss. Several changes to nozzle and metering orifice sizes were made, and acceptable performance of the vacuum system was achieved.

Three-Edge Cleaning Tests

Breathing zone monitoring had been conducted at the site trials, and had shown the machine to provide excellent capture of the grit, paint, and metal particles given off by the cleaning process. Other than spillage, the blast unit performed as expected: there was never any evidence of dust, sparks, or other contaminant being given off into the surrounding air. Even with spillage, only grit particles, not dust, escaped.

A comparison test of blast cleaning versus grinding was made using a typical DH-36 deck plate 1/2 in by 10 ft by 39 ft, 1 in long (12.7mm x 3m x 12m). The plate was scheduled to be joined along its long edges to similar plates, using the Submerged Arc Welding (SAW) process. The plates were coated with 0.8 mil (0.02mm) of preconstruction primer (“International Nippe-Ceramo”). One edge was cleaned using the Vacu-Blast three edge gun; the other was cleaned in three passes using a resin-bonded grinding disc on the root face and a “3M-Scotch-Brite” type wheel on the top and bottom surfaces. The bottom surface was cleaned “blind,” meaning that the operator held the wheel under the plate edge and moved the machine solely by “feel,” instead of bending over or squatting down and looking up at the bottom surface, which would have been much more awkward and significantly slower. As expected, coating removal was erratic, varying both in width of the cleaning pattern and in the amount of material removed where any material was removed.

The Vacu-Blast machine provided adequate cleaning of the root face and top surface of l/2-inch (12.7mm) thick plates with square-butt type edge preparation. The root face was well-cleaned, and the top edge showed a pattern extending back approximately l/2-inch (12.7mm) from the edge. Unfortunately, the blast pattern on the underside varied from 1/4 to 1/2 inch (6.3-12.7 mm) in width showing good cleaning where grit had struck the plate, but poor pattern “ consistency. This was due to dificulty in keeping the head aligned and maintaining steady motion. For these joints, the practical minimum cleaning required is 1/2 inch (12.7mm), but a wider patte~ up to l-inch (25.4mm) back from the edge, is preferable. Since the orientation of the blast nozzles was fixed within the head, the pattern will vary with plate thickness. Joints with beveled edges will show good cleaning on the face and underside, but depending on the thickness and bevel angle, may not show any cleaning of the top flat surface. These issues are discussed in greater detail in Section IX of this report.

Table 111 shows that the Vacu-Blast machine (using steel grit) was significantly slower than manual grinding. The average speed noted was 40 ipm (lm/min), about 5 ipm (0.12m/min)

slower than the average speed noted with steel grit during the vendor site trial. Some of this reduction may be accounted to the use of longer hoses, which were more difficult to drag around. While manual cleaning was nearly twice as fret, ifa more thorough job of underside cleaning was performed, some loss of speed would result. Further, if the plate had to be turned over to clean the underside, the speed advantage would clearly lie with the three-edge system. These issues are rhetorical, however, since the slow speed, uneven blast pattern and awkward nature of the three-edge gun do not make it a serious competitor to manual grinding in its present implementation as a hand-held device. The fixed orientation of the nozzles in the blast head allows the uneven blast pattern to occur if the head is "wiggled" or rotated as it is moved along the edge of the plate. The design of the guide wheels does not prevent such wiggling, and the lack of adequate bearings made it difficult to move the head smoothly along the plate edges.

Table IIL 3-Edge Cleaning Project: Shipyard Trial (Bath Iron Works, Bath ME) (Vendor Site Trial Data Included for Comparison)

Method	Length, in (m)	Time (min.)	Speed ipm(m/min)	Remarka
Plate Cleaning (3-Edge, Steel Grit):				
Face: Manual Grind Edges: '3M Scoth-Brite"	469 (12)	6.3	74.44 (1.9)	3 separate passes, Underside not well-cleaned
Vaeu-Blast UniL 3-Edge gun	469(12)	11.65	40.26 (1.02)	Underside pattern variable in width
Joint Re-cleaning (Single Surface, Steel Grit):				
Manual grind	552 (14)	480	1.15 (0.03)	Avg. of 8 labor hours to clean a 46-ft (14m) groove joint
Vaeu-Blast Unit, Utility gun	144 (3.7)	4	36 (0.93)	Average sp@ 36 (0.9m) test plate assemblies, total of 4.
Three Edge Vendor Site Trials (KeIco Sales & Engineering, Norwalk, CA)				
Steel Grit	4,526 (115)	89.2	54.6 (1.3)	35 total pieces variouS thickness plate, T, and I-beam seetions. Max. length individual piece, 139 in. (3.5m)
Aluminum Oxide	2,354(76.5)	28.9	8L7 (2.1)	
CrystalGrit	1,940 (49.3)	23.2	83.6 (2.3)	

Flat Surface Cleaning Tests

Two flat surface guns were evaluated, a "long gun," capable of making 2 inch (50.8mm) cleaning patte~ and a "utility gun," limited to a 1/2 inch (12.7mm) wide pattern. Both guns were deemed unsuitable for paint removal on DDG structural units which were completely fit, with stiffeners, intercostal, headers and miscellaneous structural elements all tack welded together. The small size of the tees and other shapes allowed only limited access due to the size of the gun and hoses. The long gun was used for a few trial passes, removing paint from unobstructed plate, but no timehpeed measurements were made since it was readily apparent that abrasive wheel devices could remove primer from the flat areas more rapidly, and had no problem with access in tight places.

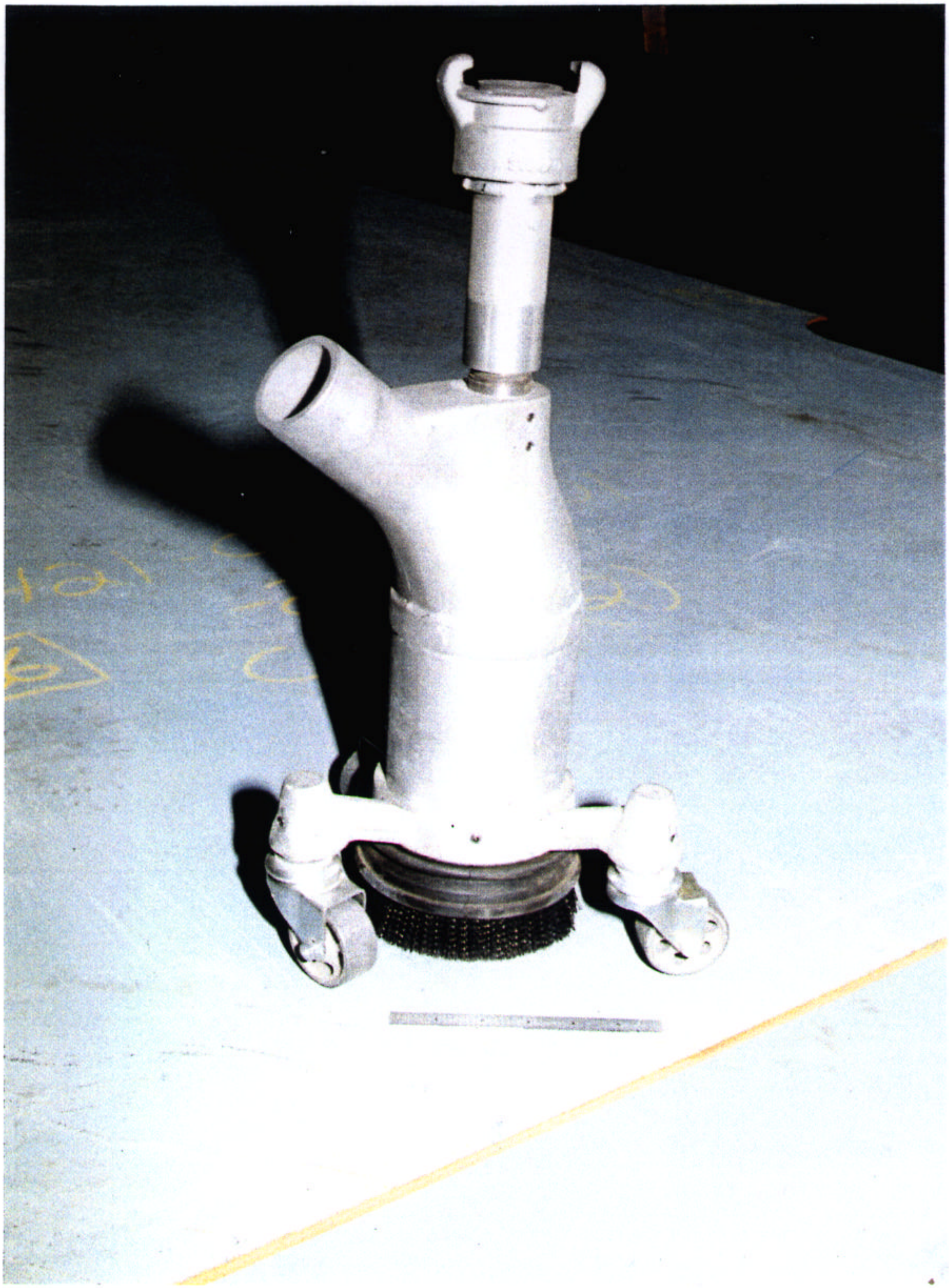


Figure 33. "Long gun" for flat surface blasting.

The utility gun was seen to be a successful solution to one frequent problem. Long butt welds, fit up for mechanized welding over ceramic backings, often were not welded before plate edges began to rust, especially in humid weather. Manual grinding was time consuming and diflicult due to the need to carefully clean all of the bevel-edge surfaces without unintentionally enlarging the root opening. Test plates were set up, as in Figure 34. The blast pattern of the utility gun could be directed on each plate “near side” surface and bevel face, allowing the cleaning of the side to be welded in two passes, one for each plate.

To prevent grit from escaping through the root opening and into the adjacent space, and to maintain good vacuum, some means of sealing off the root opening is needed On joints with the ceramic backing already applied (see Figures 35 and 36), the ceramic would not be badly eroded, and an exceptionally clean surface would result (as in Figure 37). If travel speed was too slow, excessive erosion of the ceramic material would occur, as showning,Figure38. With horizontal-position groove joints, grit could be trapped between the lower edge of the ceramic and the plate, and hold the ceramic away from good contact with the plate. This would allow an excessive backbead shape to form. Tests were made using metal bars, adhesive tapes, and rubber electrical splicing tape held in place by green masking tape. Metal bars took more time to apply and needed to be wedged into place. The blast stream could easily cut through a single layer of green tape, but two layers of the green tape contained the abrasive if a travel speed of 36 ipm (0.9m/rnin) was maintained. The best compromise for durability and speed of application was a strip of l/16-in. (1 .6mm) thick rubber electrical splicing tape held in place by a single layer of green masking tape as shown in Figures 39-43.

As shown in Table III, the utility gun showed a dramatic speed improvement over manual grinding. It must be noted that the manual cleaning rate is based on an average of actual time spent on several joints, while the utility gun was used in a “bench top” scenario, in which only the cleaning function was timed. Even though additional time would be needed for machine set-up and for application and removal of the sealing tape, it can be expected that overall performance would show an significant improvement with an appropriately sized blast cleaning unit.

Disposal of Waste Products

A major feature of the recirculating grit blasting system is elimination of airborne dust emission. The system separates dust and spent grit from recyclable grit. Samples of the fines collected were subjected to a toxicity characteristic leaching procedure (TCLP). Results of this test indicate that this dust has the (expected) same characteristics as the swarfproduced by grinding, and thus while actual requirements for disposal classification may vary with local regulations, the disposal procedures for the collected dust and fines should be no different than those required for disposal of grinding dust. See Appendix B for greater detail on this subject.

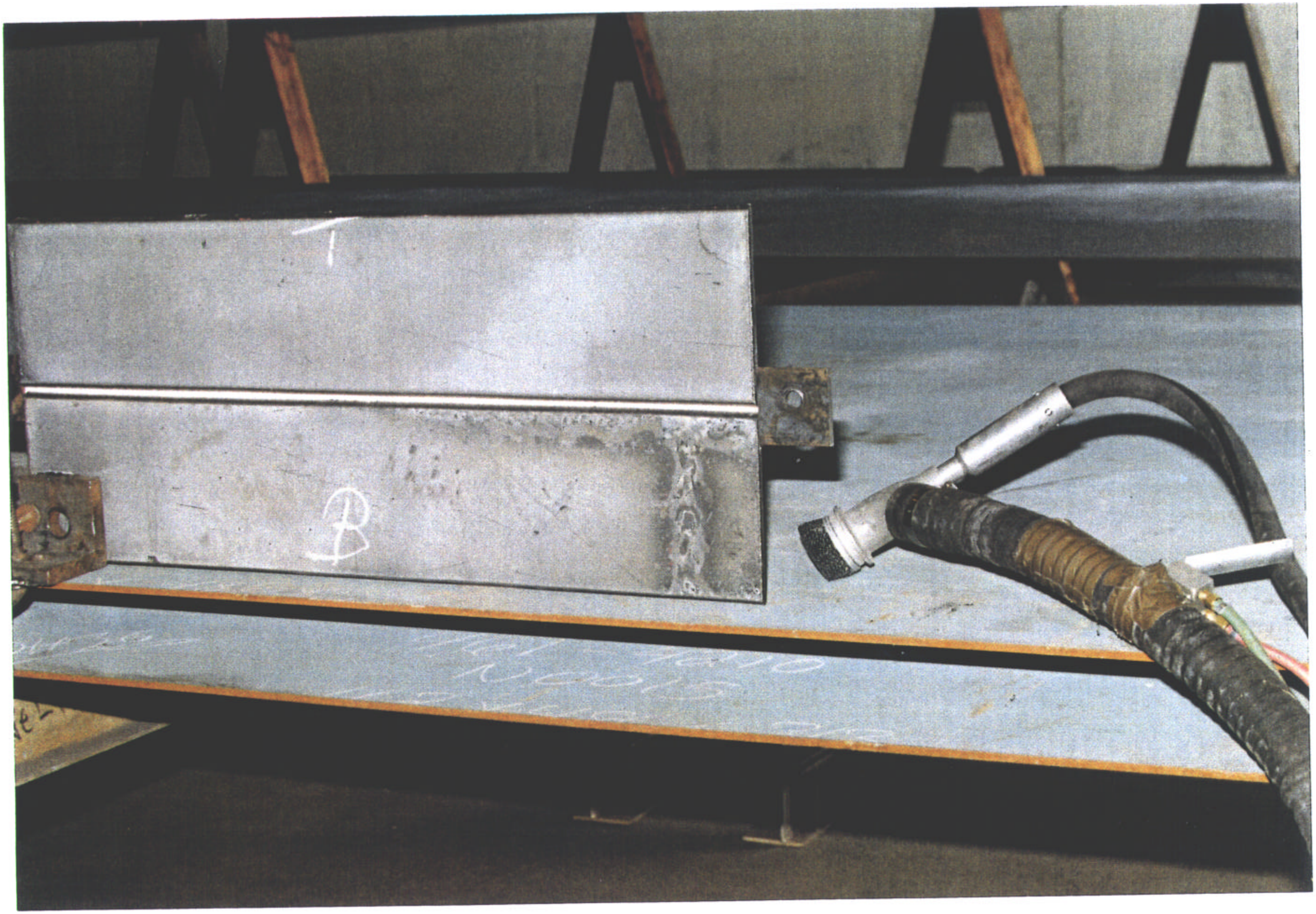


Figure 34. Test assembly with ceramic backing before blasting with "utility gun."

Figure 35. Close-up of ceramic backed assembly before blasting.

Figure 36. Blasting in progress on assembly with ceramic backing.

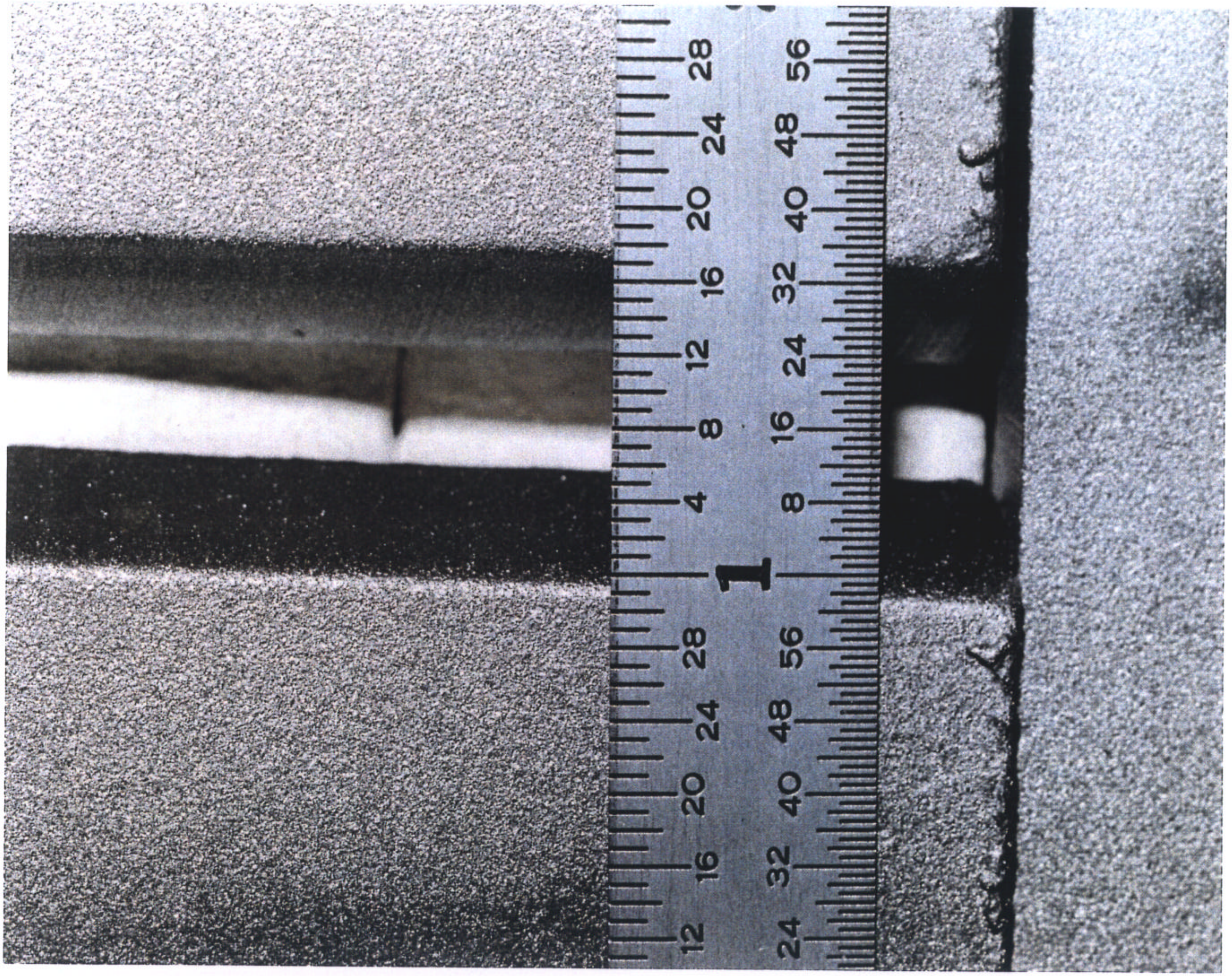


Figure 37. Close-up of plate edges after cleaning.

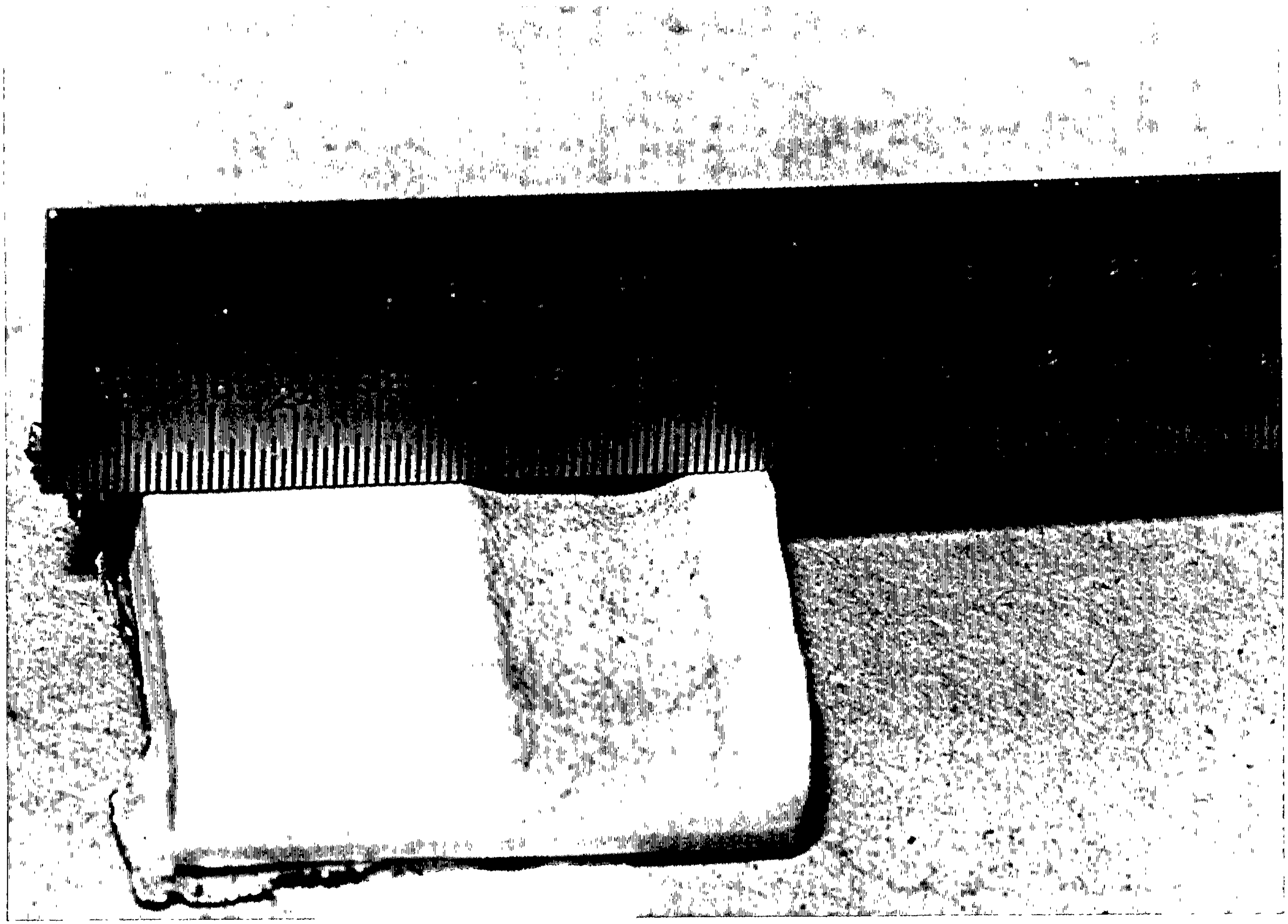


Figure 38. Erosion of ceramic after blasting at low travel speed.

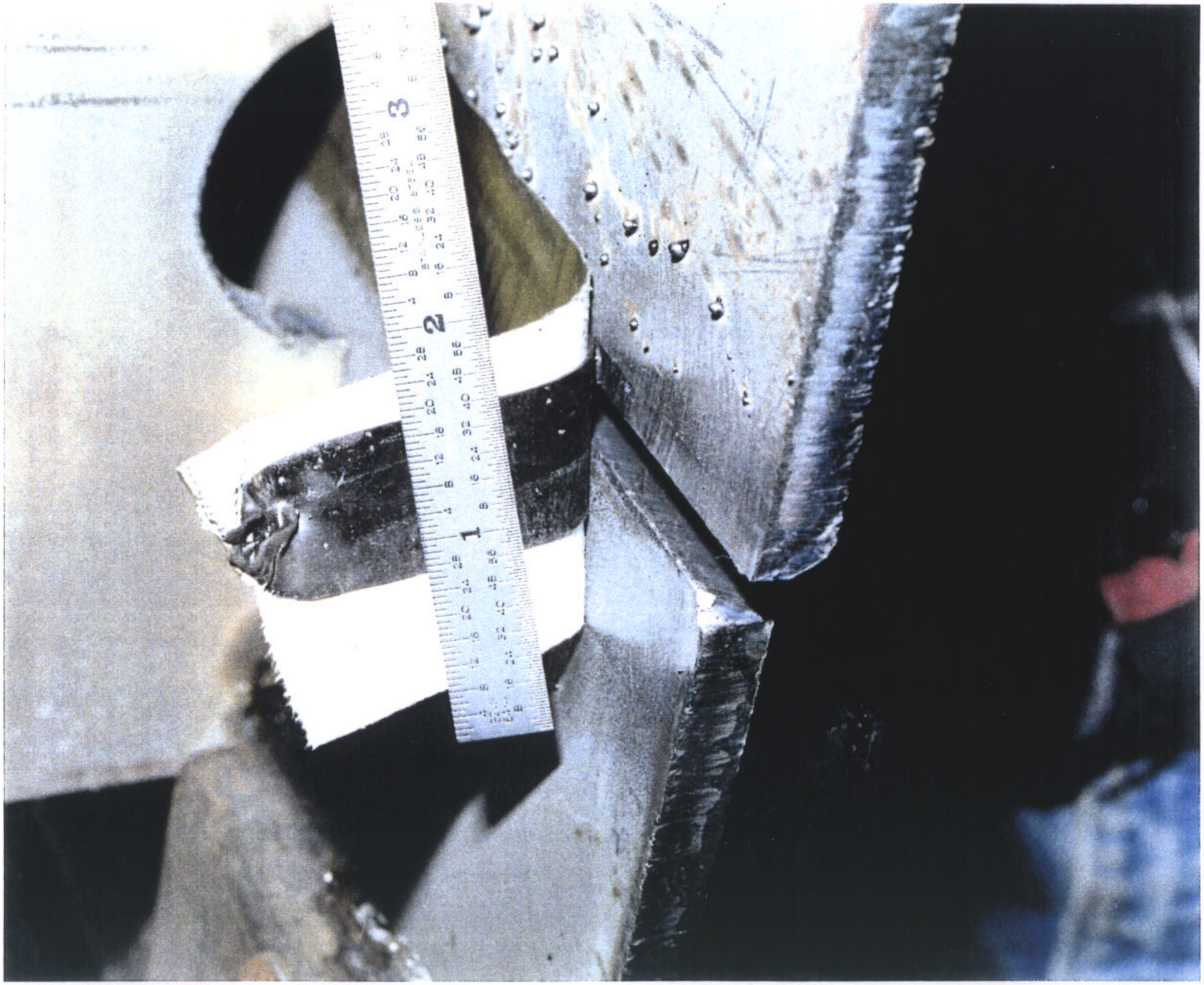


Figure 39. Tape for sealing root before blasting.

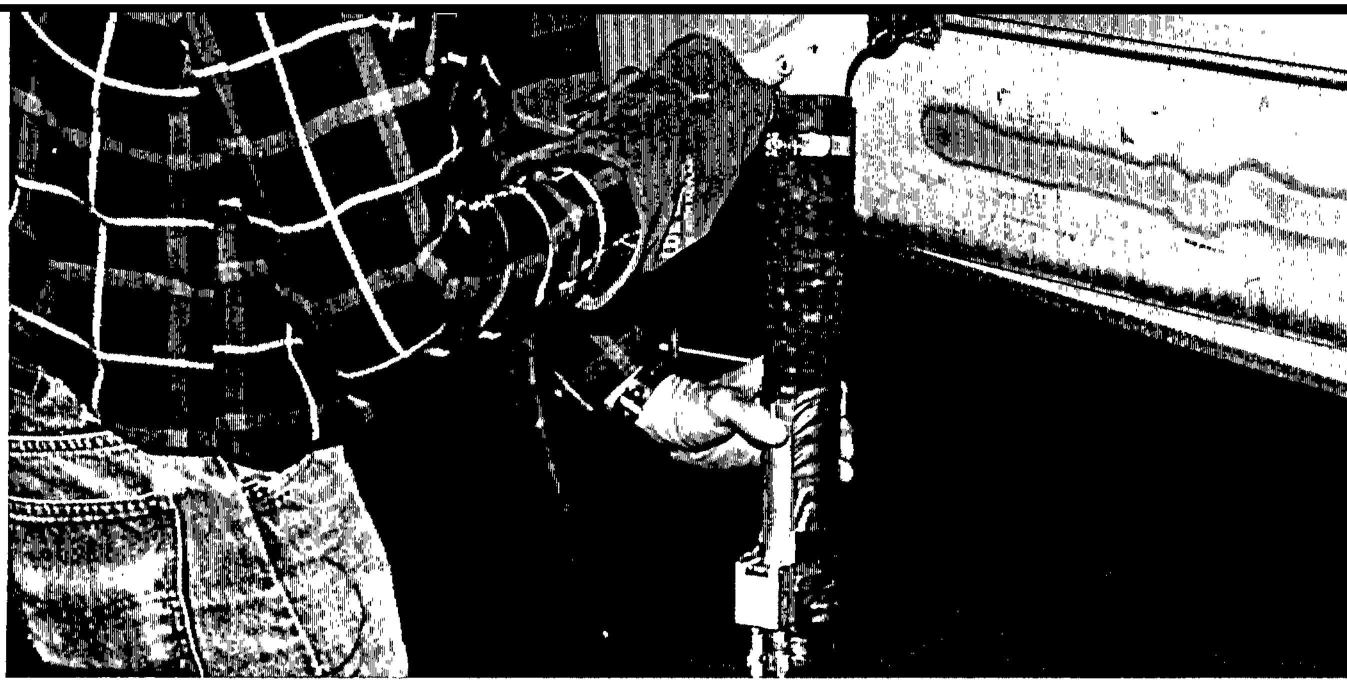


Figure 40. Cleaning assembly backed with tape to seal root.

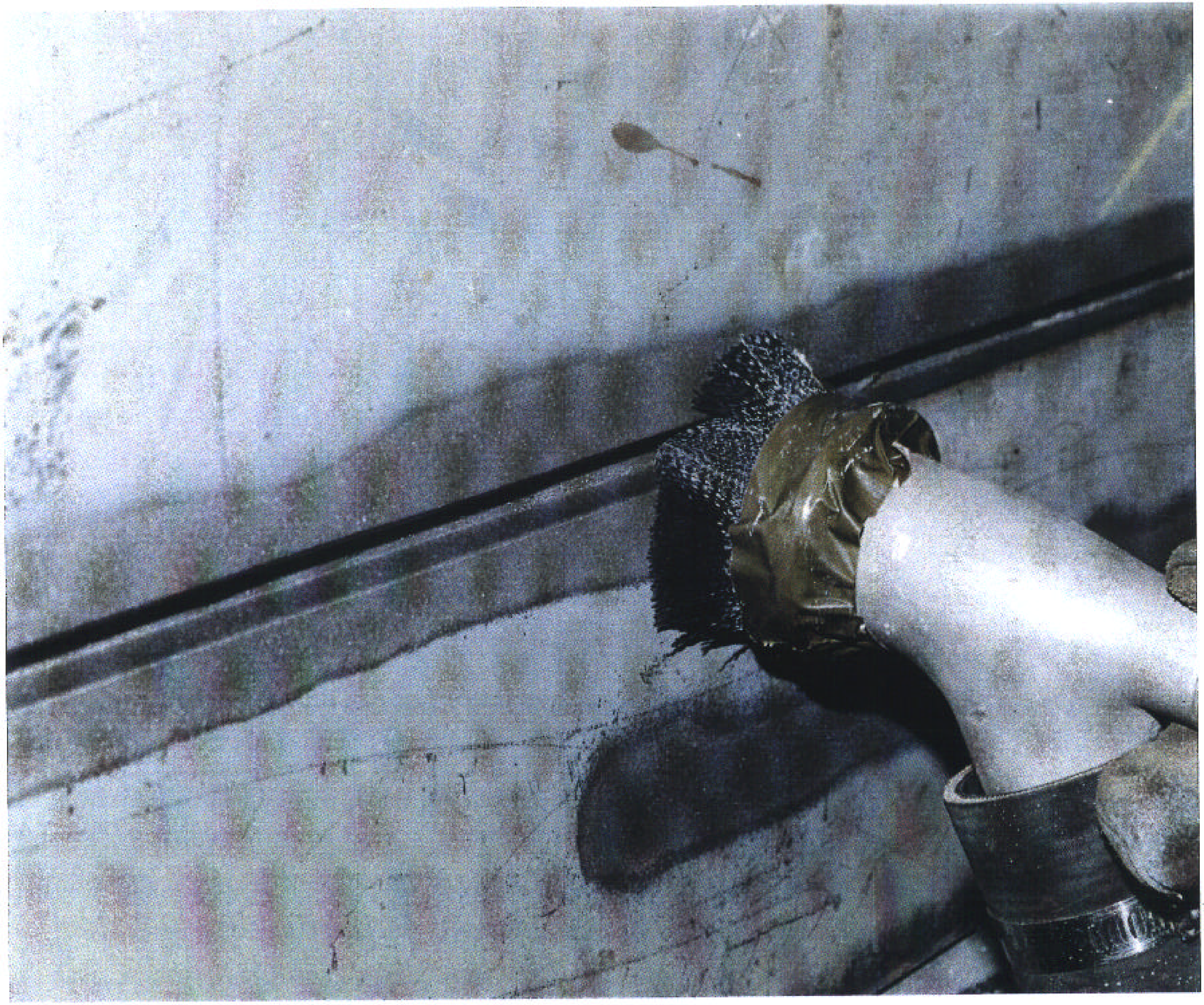


Figure 41. Close-up of blasting in progress against rubber tape in root.

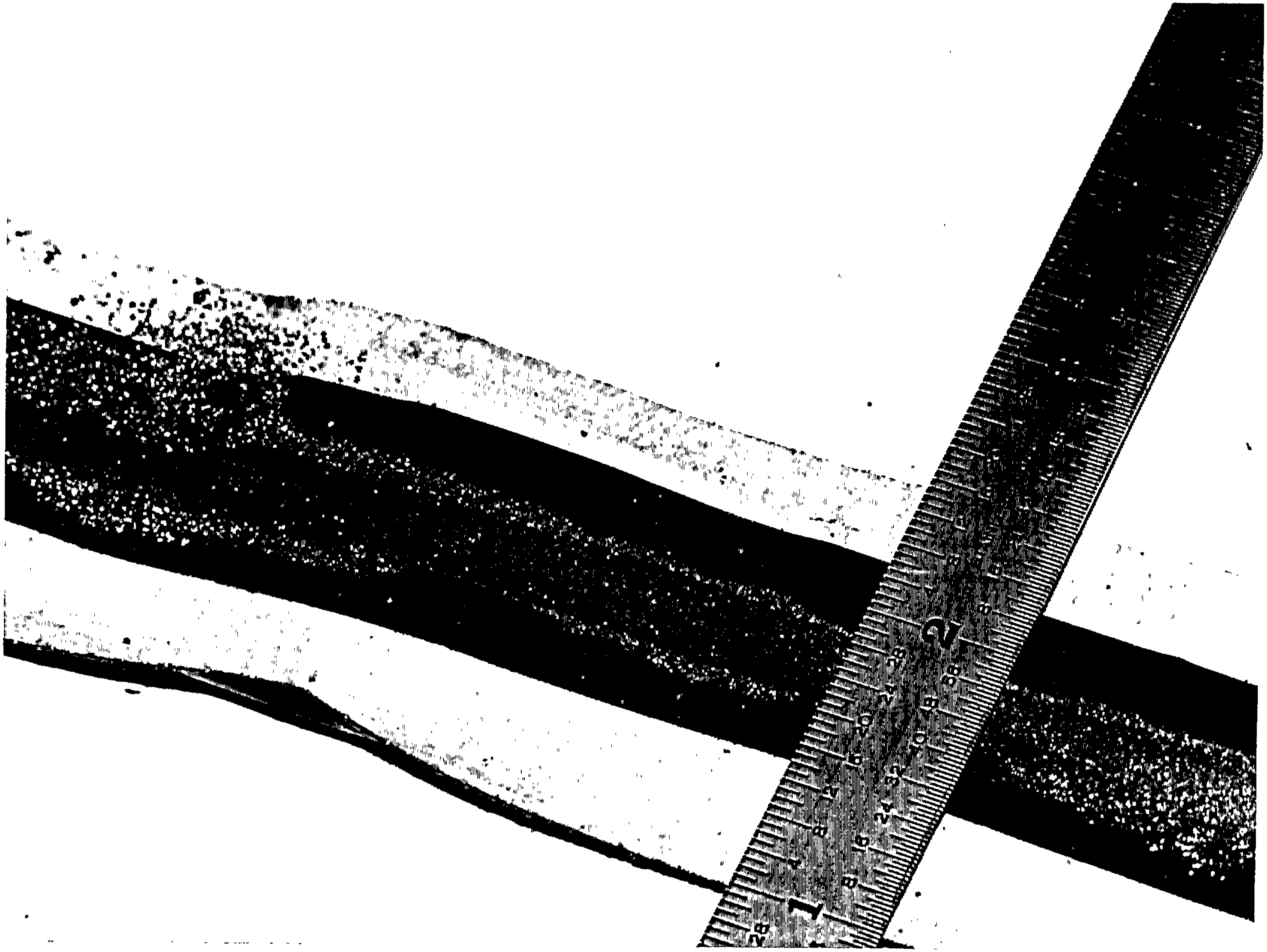


Figure 42. Tape sealer after blasting.

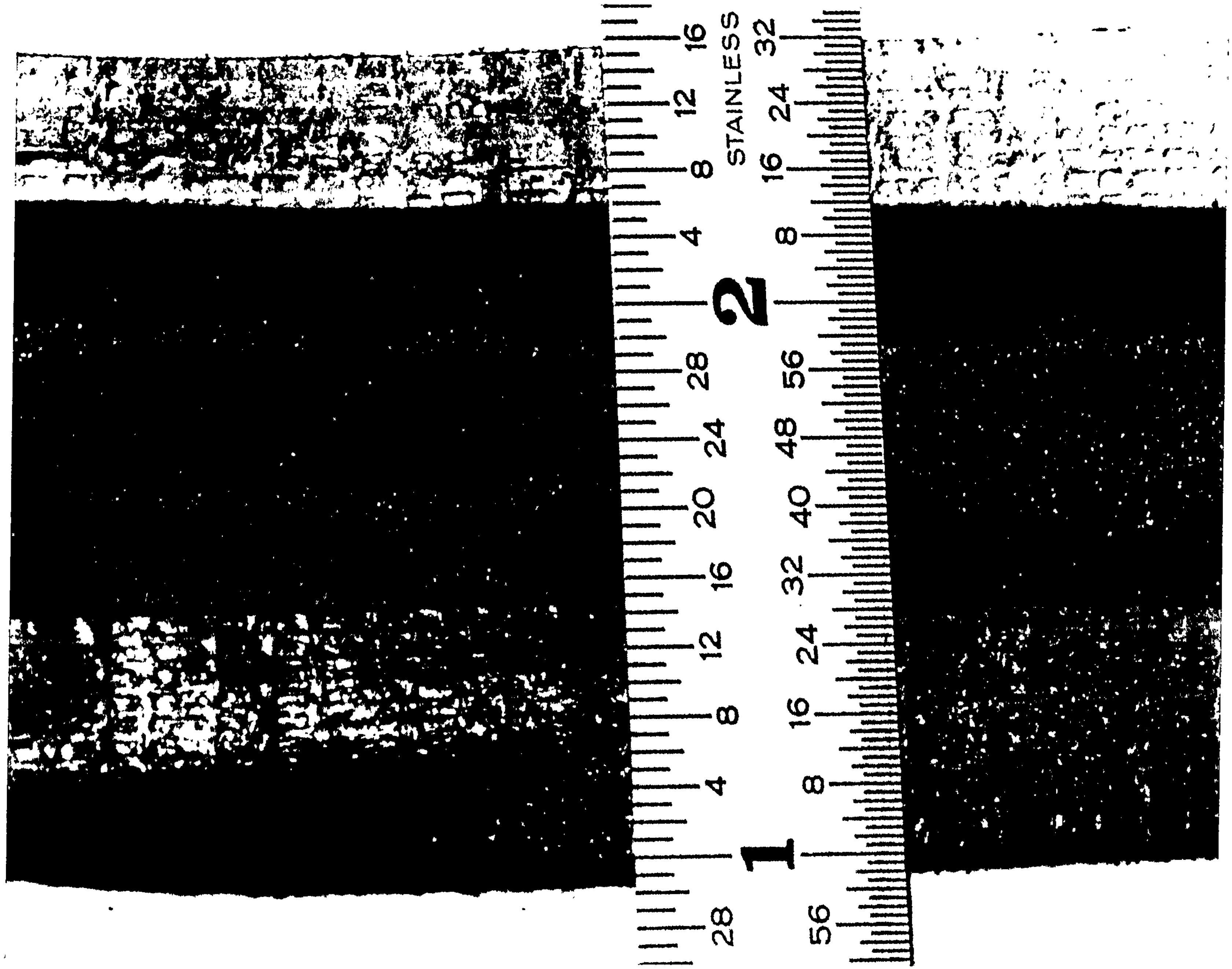


Figure 43. Close-up of tape after blasting.

VIII. EVALUATION OF CLEANED SURFACES

This portion of the project was not part of the scope of work of the original proposal. The primary intent was to evaluate the quality of the surfaces produced using only visual inspection. During the review phase, a search was made for reference material with more detailed information about surfaces produced by various cleaning methods. Since no such references were discovered, this portion of the project was included to provide some data for future reference.

Surfaces cleaned by the various methods were qualitatively evaluated using a Scanning Electron Microscope (SEM). The general shape and pattern of the cleaned surllaces could be readily see% and the presence or absence of suspected contaminants was noted. Micrographs of surfaces produced by many of the methods examined in this study are presented in the following pages. In addition to cleaned surfaces, examination was made of the typical steel surfaces both after blasting on the mechanized blast and prime line, and in the as-primed condition.

It was beyond the scope of this project to exhaustively characterize the nature of the contaminants, but a limited amount of Energy Dispersive X-Ray (EDAX) analysis was performed, showing significant levels of zinc as residual from the IZ primers. This would be a good area for fi.nther study, especially if the effects on weld quality and arc stability of different residual materials were evaluated. Surface characteristics of cleaning methods vary substantially, and this may have implications for high speed welding. Most shipyards receive plate and shapes in mill-condition, with rust and scale which is removed by mechanized blasting before the application of pre-construction primer. Grinding and sanding smear and flatten the peaks of this prior blast surface, and residual amounts of primer in the “valleys” are trapped under the edges of this displaced material. Grit-blasted surfaces appear to be generally cleaner.

As a very informal and admittedly subjective follow-up test, comparison welds were made on two IZ-PCP primed plate assemblies, one of which had been cleaned by grit-blasting, and the other by grinding. The assemblies were pairs of 3/8 in (lOmm) thick plates setup for ceramic-backed one-side welding. Root opening, bevel angles, ceramic type and welding position (horizontal (2G)) were virtually identical between the two assemblies. The Gas Metal Arc Welding, Pulsed Arc (GMAW-P) process was used, with 0.045 in. (1.2mm) diameter E-70S-3 electrode. On the grit-blast plate, the arc was noticeably quieter, smoother, and less prone to spatter than on the ground plate. Furthermore, a greater amount of smoke was seen to issue from the arc area while welding the ground plate, presumably from the breakdown of primer residues.

While this is hardly conclusive, there is a strong possibility for a definite causal link in the observations. First, the SEM photos do indicate that the grit blasting produces a cleaner surface. Second, the surface produced by grit blasting is populated with a high density of sharply pointed features which are good emitters of electrons under the reverse polarity field of the welding arc. The grinding process, on the other hand, smears the peaks of the original blast profile over islands of residual primer. As these smeared areas come under the arc, they are likely to melt erratically and cause arc instability. Thus, grit blast cleaning may offer benefits for certain applications, such as high-speed small fillet welding, where arc stability maybe important for producing well-formed, porosity-flee welds with consistent leg length.

Procedure

In some cases, SEM evaluation was done within one day after the cleaning operation was performed. Moderately-large sections (having a large thermal mass to insure against overheating) were taken ilom the plates and shapes cleaned. These pieces were brought to the SEM facility, and cut into of the maximum size allowed by the SEM stage. All cutting was done with hand hack-saws or portable band saws, without lubrication. In most cases, no “flash-rust” had appeared on the surfaces before the examination by SEW but in a few instances, schedules did not allow for quick transport to the facility, and some flash rust had appeared.

Small specimens were cut from test pieces and mounted for evaluation using typical mounts. In most cases, and especially on samples cut from surfaces having prior epoxy coatings, a film of carbon was applied by sputter-coating, due to the tendency of non-conductive materials to “charge.” It was noted that even the zinc-based primers had a tendency to charge.

Observations

- Grit blasting produced the cleanest surfaces; surface quality was similar for both steel grit and aluminum oxide gtit. While residual areas of primer were seen, these were fewer in number than those of other methods.
- Laser stripping caused a more complete breakdown of primer than other methods, but appeared less effective, because of the presence of islands of melted metallic components of the inorganic zinc primer. Since the laser treatment was not followed by any clean-up tl.mctio~ these metallic islands were not removed. Other studies have confirmed the effectiveness of laser stripping at breaking down and vaporizing organic coatings, and the breakdown of metallic pigments, leaving metallic elements as melted islands. A purely organic primer may not have shown such characteristics; but since organic compounds could not be evaluated using ED- this question would be dependent on further work.
- Q The three-head multi-brush (Desco Web Descaler) appeared to produce cleaner surfaces than manual grinding and wire brushing. The quality of paint removal by the multi-brush unit depended on the prior surface. The multi-brush was prone to leave residual primer in the valleys of flame-cut surfaces of I/T sections, and was not as effective as grit blasting in removing the primer from the radius area of the I/T flange stubs (see Figure 2).
- Grinding was more effective than sanding for primer removal, but smearing was observed on the ground surfaces as well. The effectiveness of both grinding and sanding were dependent on the roughness of the surface prior to the application of the coating, similar to multi-brushing.
- EDAX of as-primed plate (no cleaning) showed approximately 3 5% zinc, the nominal content of the zinc-based primer used for most of this program. EDAX of primer residues on grit blasted surfaces showed a 17.7% zinc content, while the metallic islands on the surface of the laser-treated specimens had zinc contnent on the order of 7.3%

“ Micrographs from selected processes appear in Figures 44-57. Edax analysis reports are presented in Figures 58-60.

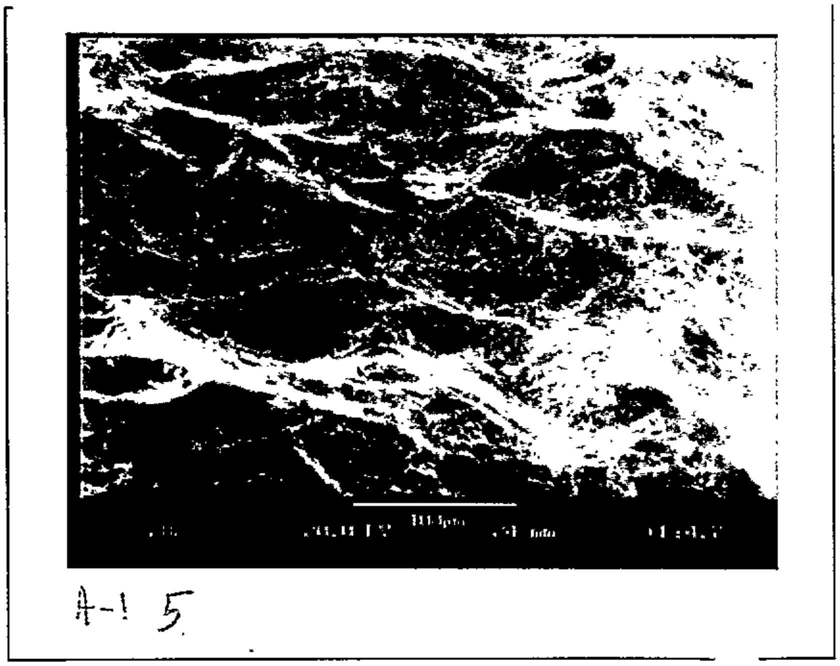


Figure 44(a). Surface of structural steel as produced by blasting with G-40 steel grit on mechanized clean and prime processing facility. (282x)

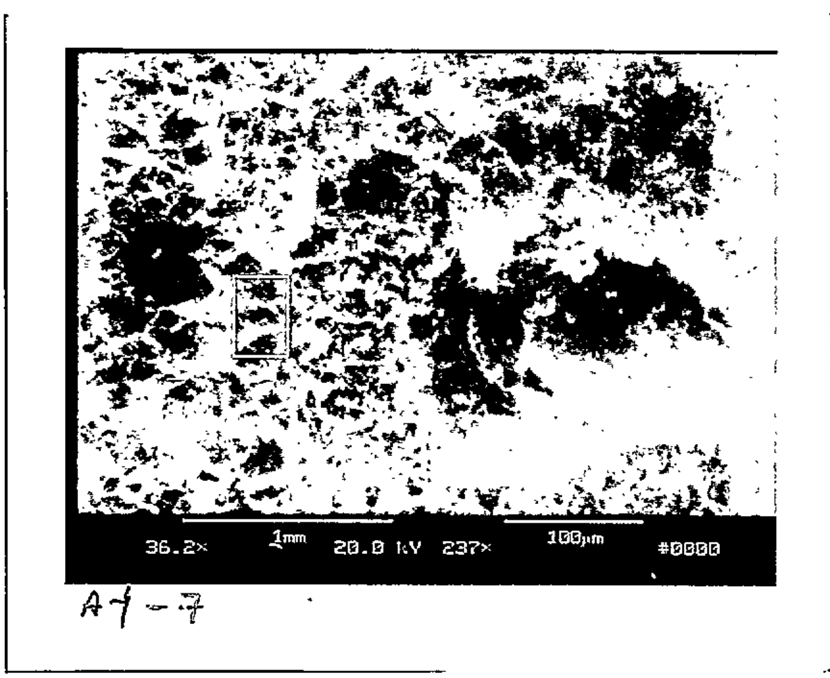


Figure 44(b). Different view of same surface as 44(a) above, showing residual material and small "tear" on surface. Split screen at 36x and 237x.

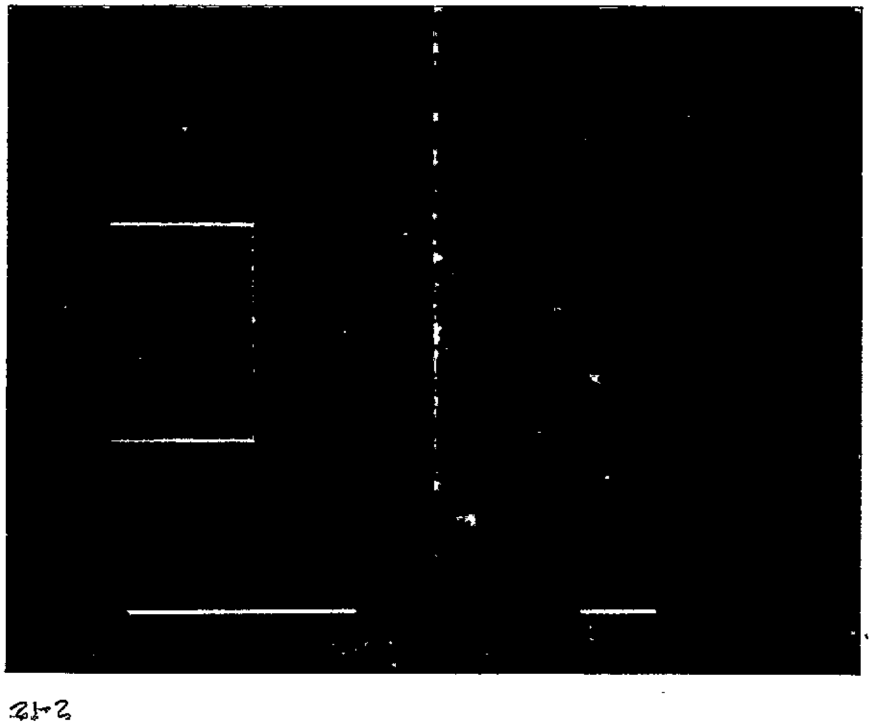


Figure 45. Surface of inorganic zinc primer after application by mechanized clean and prime line. Split screen at 30x and 99x.

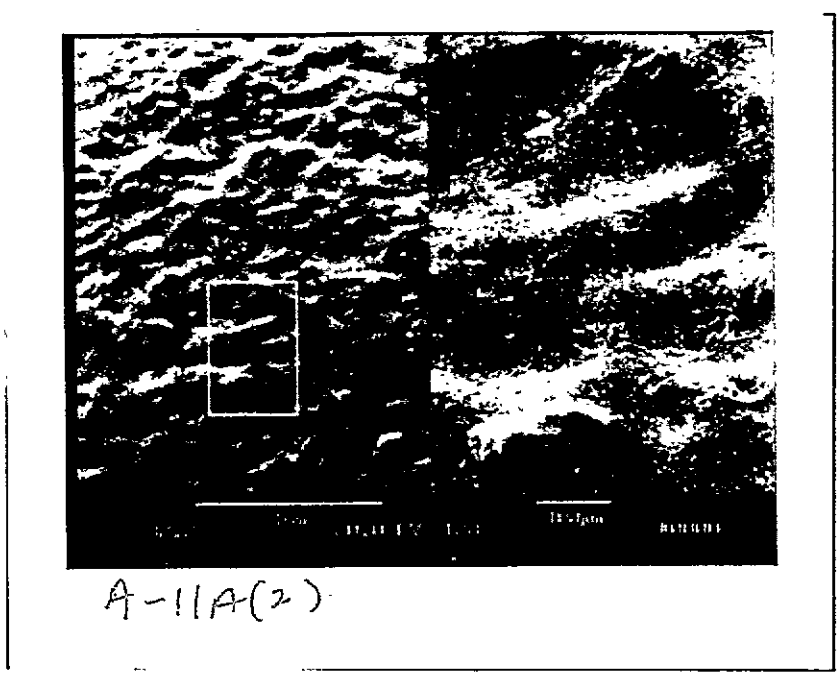


Figure 46. Epoxy pre-construction primer as applied by mechanized clean and prime facility. Split screen at 32x and 128x.

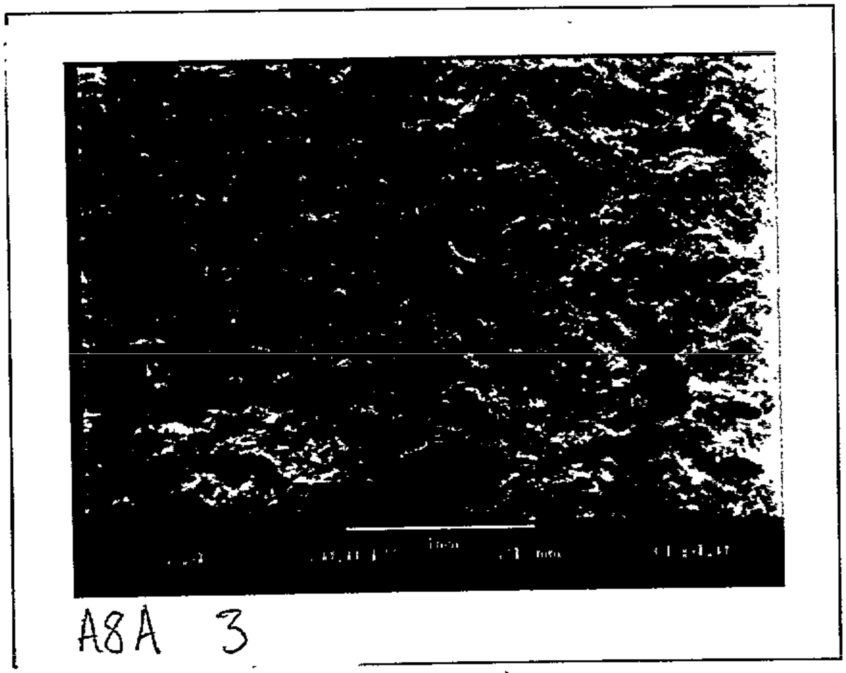


Figure 47(a). "Nippe-Ceramo" primer as applied by mechanized clean and prime facility. 32x.

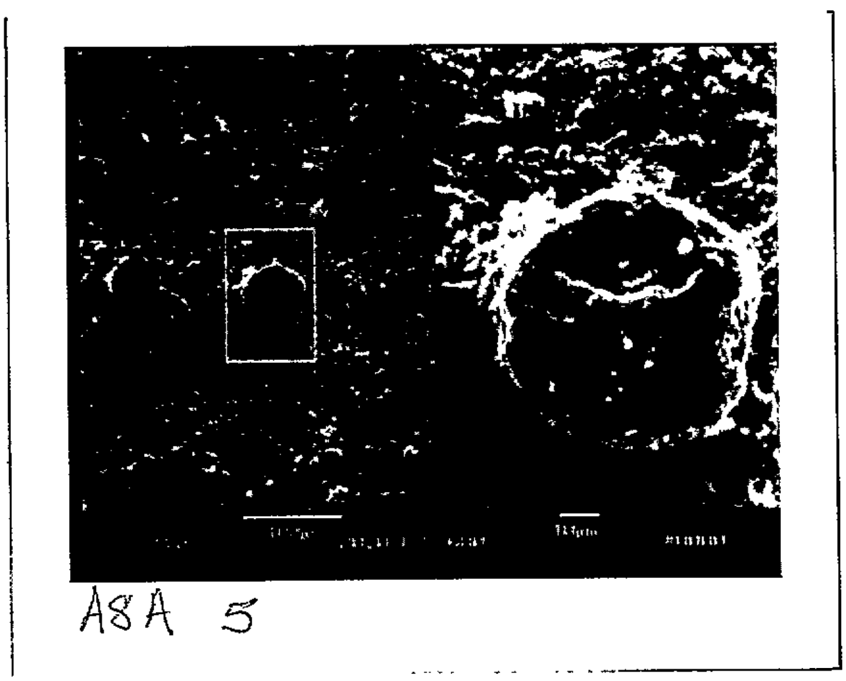
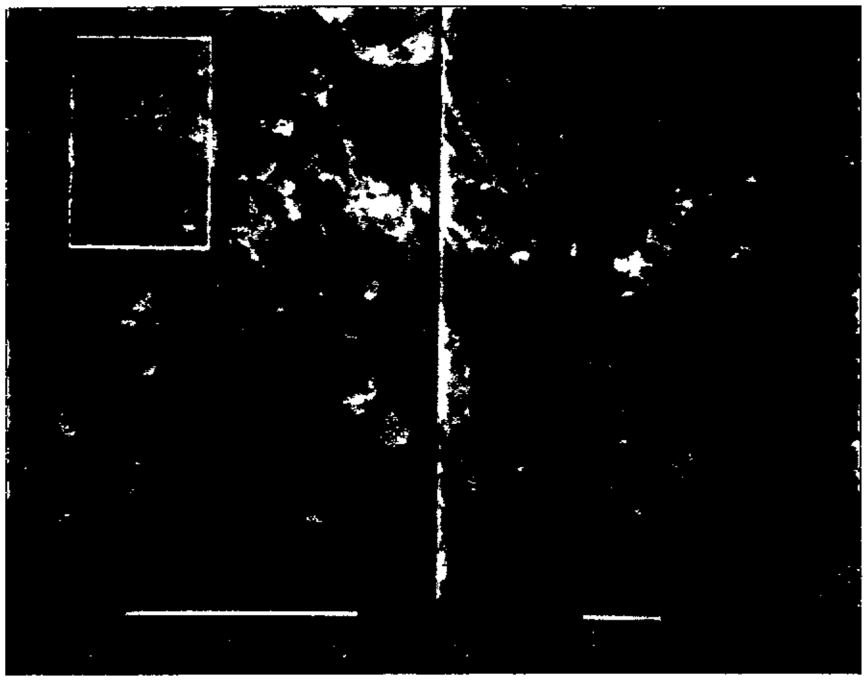
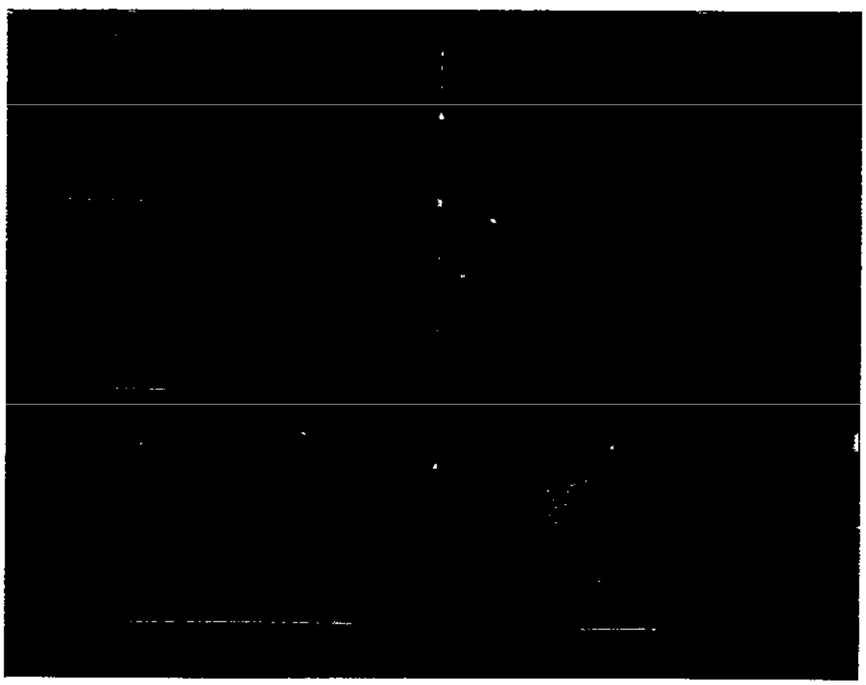


Figure 47(b). View of 47(a) at higher magnification. Split screen at 170x and 680x.



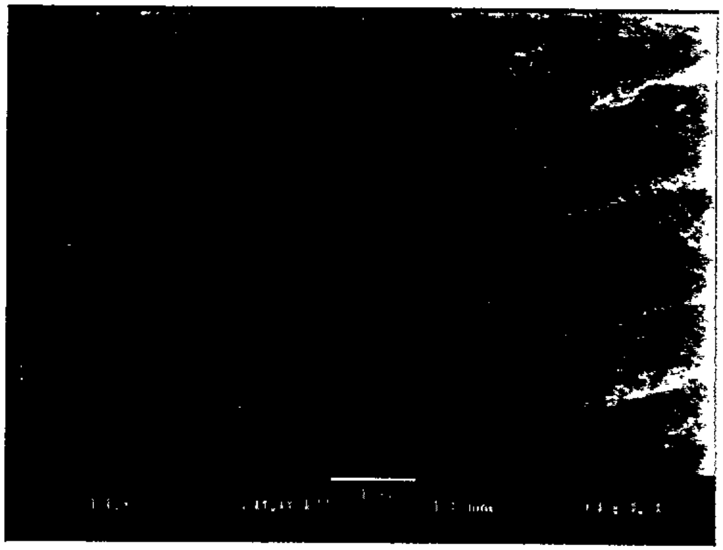
-20

Figure 48. Surface after sanding inorganic zinc primer. Split screen at 30x and 103x.



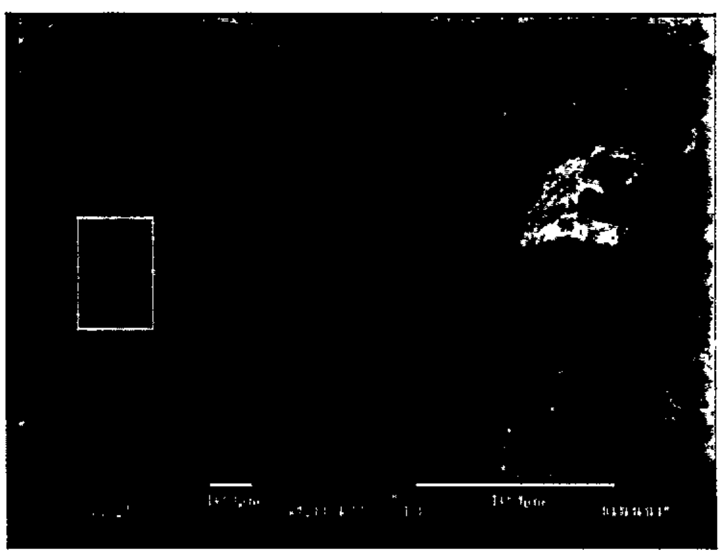
10

Figure 49. Surface after grinding inorganic zinc primer. Split screen at 30x and 114x.



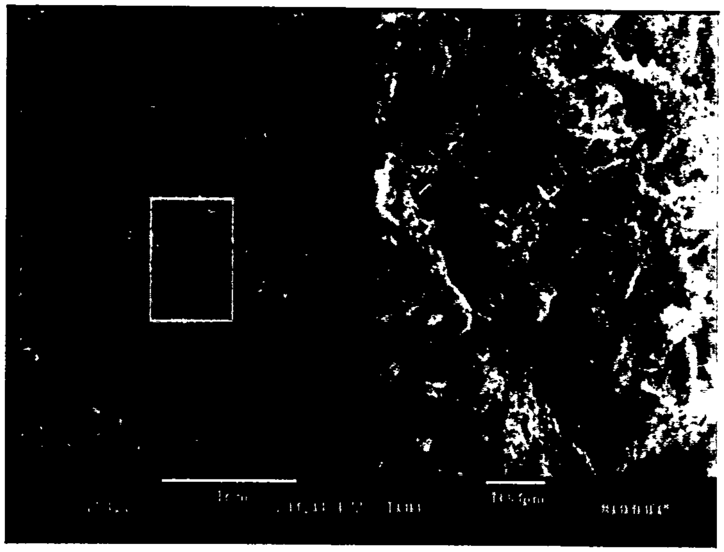
AZ 2

Figure 50(a). Surface of I/T after needle gunning, lower magnification. Rippled area to right is kerf surface from deflanging. Oblique line from upper left to lower right is transition at radius, showing residual material. 14x.



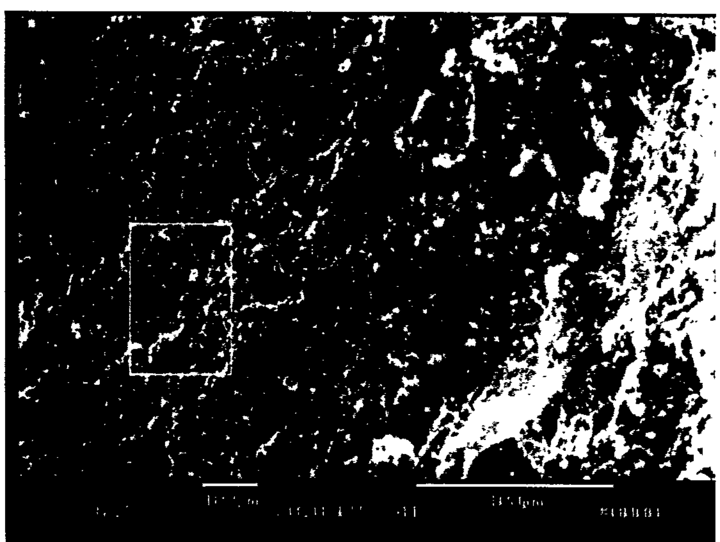
AZ 5

Figure 50(b). Higher magnification of 50(a). Smeared material is evident, as are islands of residual material. Split screen at 72x and 343x.



A-9 6

Figure 51. Surface produced by blasting with G-50 steel grit; inorganic zinc primer. Split screen at 23x and 100x.



A-11 16

Figure 52. Surface produced by blasting with G-50 steel grit; epoxy primer. Evidence of residual material. Split screen at 97x and 300x.

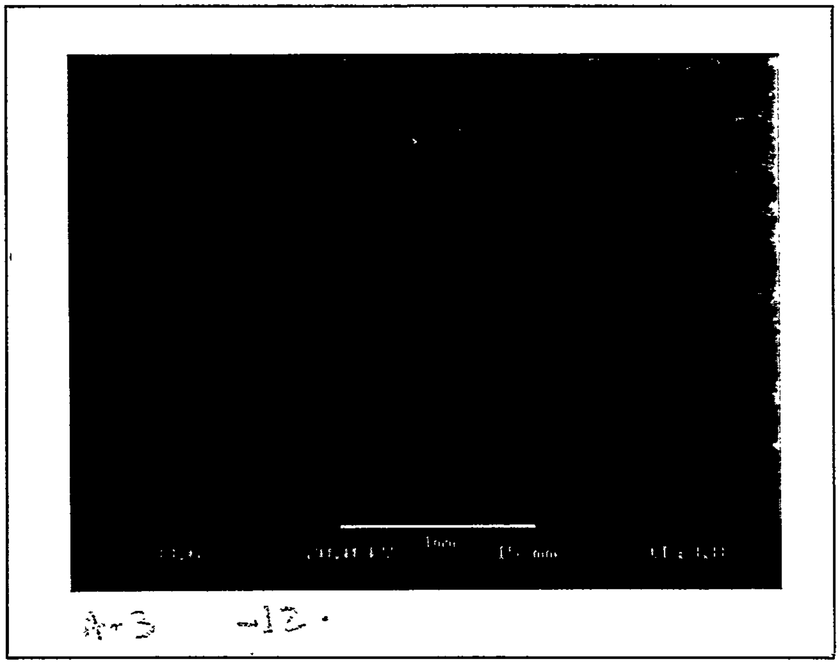


Figure 53(a). Surface produced by CO2 pellet blasting; IZ/PCP. Some evidence surface working has taken place; depressions appear larger than those of Figure 44. Ridges of I/T flame-cut kerf can be seen. 33.6x.

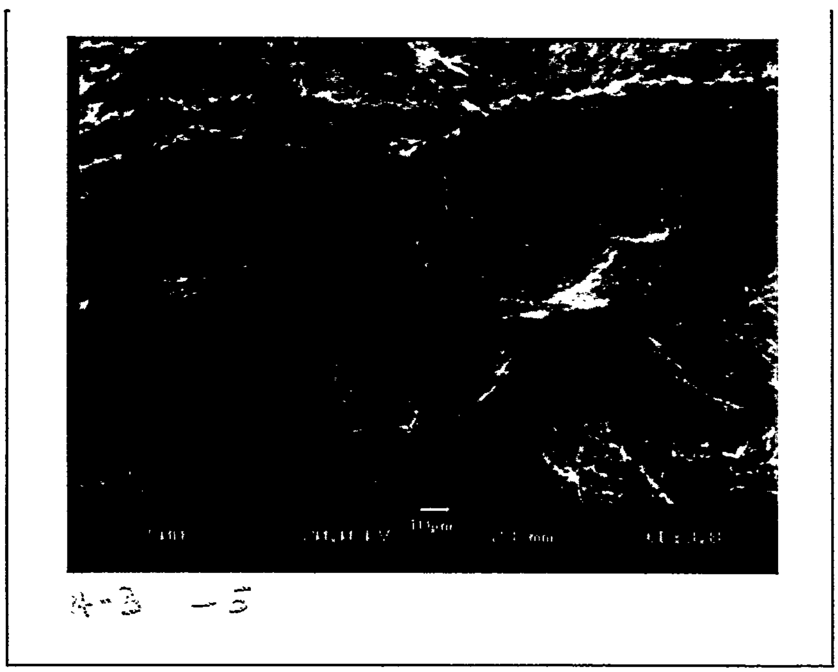


Figure 53(b). Surface produced by CO2 pellet blasting of IZ/PCP. Higher magnification of 53(a), showing enlarged crater. 500x.

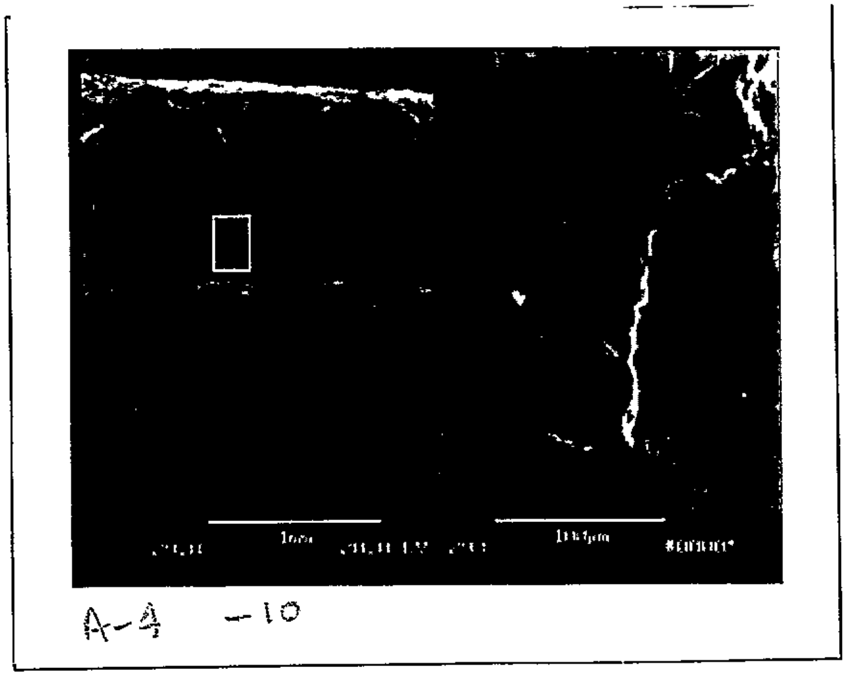


Figure 54. Surface produced by CO2 pellet blasting on edge of epoxy-primed hot-rolled Tee (split I-Beam). Evidence of residue at deformation produced by web shearing. Split screen at 29x and 293x.

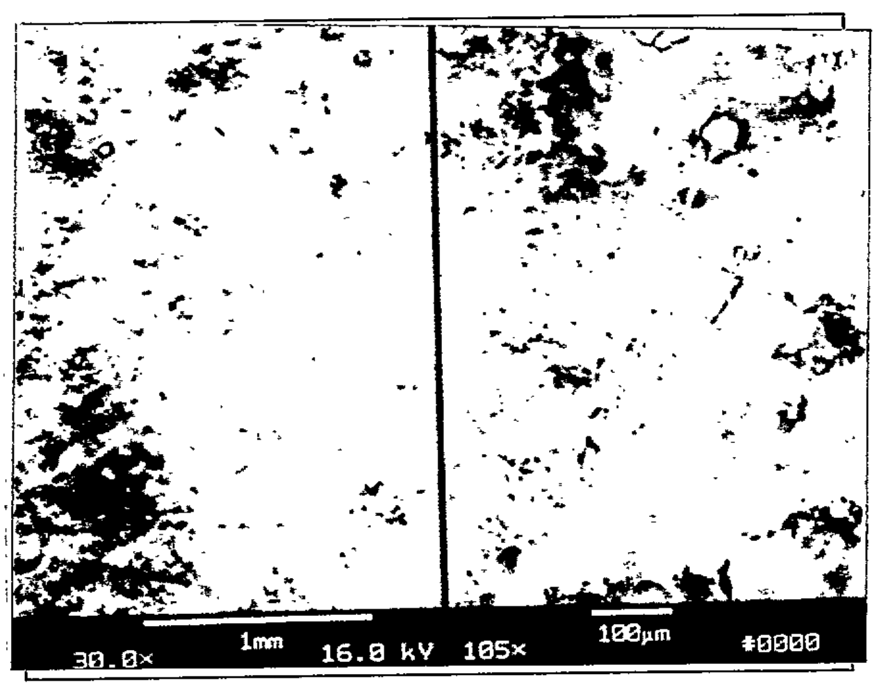


Figure 55. Surface produced by laser stripping inorganic zinc primer at 1350W and 60 ipm. (1.5m/min) Split screen at 30x and 105x.

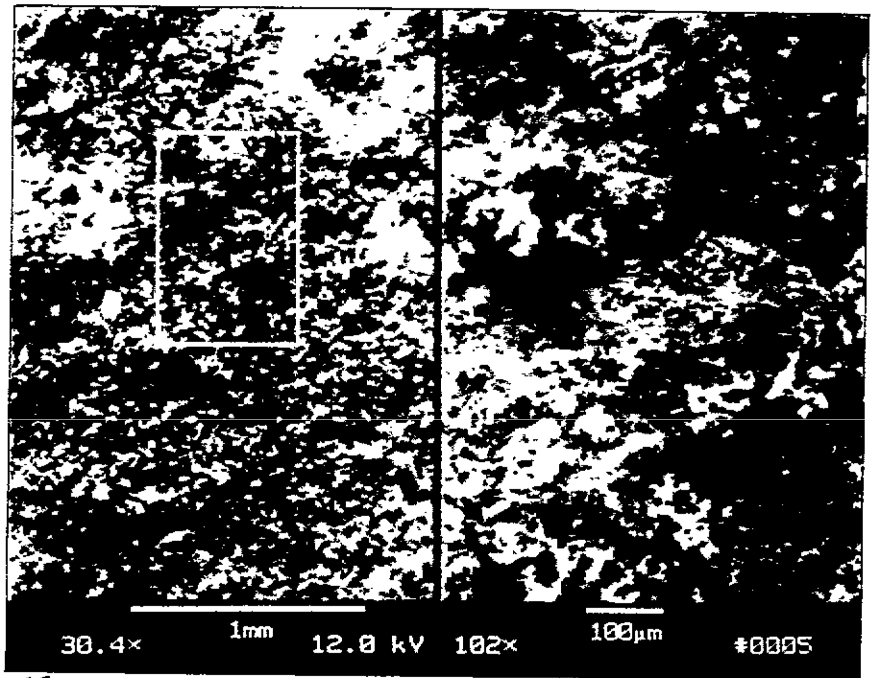


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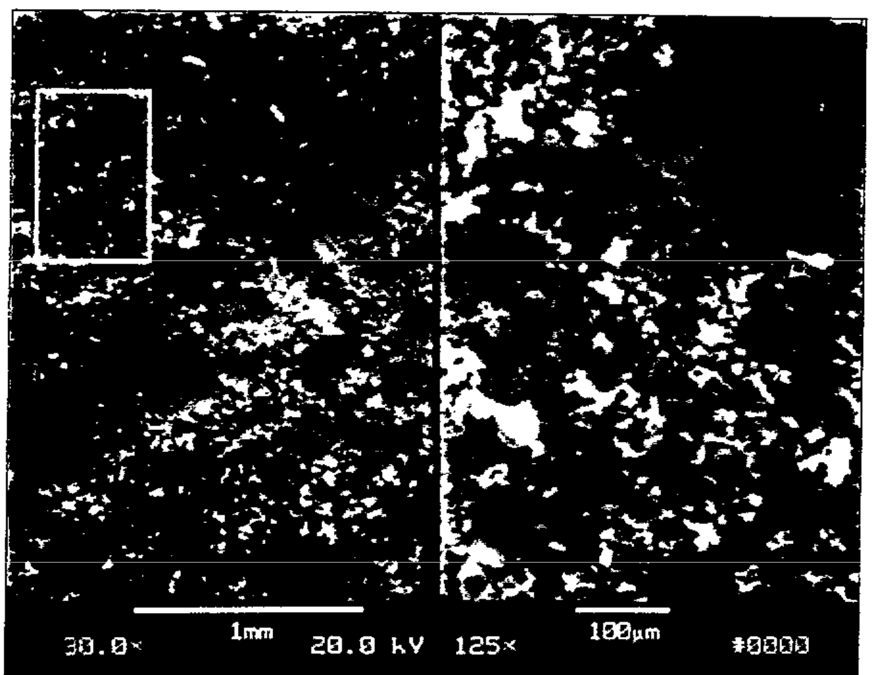
Figure 56. Surface produced by laser stripping inorganic zinc primer at 1350W, 90 ipm. (2.3m/min) Split screen at 30x and 102x.



26

Figure 57. Surface produced by laser stripping inorganic zinc primer at 2200W, 90 ipm. (2.3m/min) Evidence of melted material. Split screen at 30x and 125x.

EDAX Results (No Treatment)
Sample 21
Untreated Paint Surface

```
INTE-%-ZAF:
LABEL =
15-JUN-94    08:22:53
  100.000 LIVE SECONDS
KV= 20.0   TILT= 30.   TKOFF=33
           ZAF CORRECTION
```

ELEM	K	z	R	F
NAK	0.0004	1.056	0.197	1.002
ALK	0.0081	1.050	0.3S2	1.006
SIK	0.1222	1.080	0.471	1.003
P K	0.0397	1.052	0.483	1.001
AGL	0.0087	0.870	0.876	1.006
CAK	0.0323	1.056	0.867	1.012
TIK	0.0039	0.965	0.926	1.032
FEK	0.2532	0.96S	0.983	1.043
ZNK	0.3232	0.936	0.979	1.000

ELEM	CPS	WT% ELEM
NA K	0.4400	0.18
AL K	17.1100	2.17
S1 K	307.06(30	23.97
P K	76.5200	7.80
AG L	6.6800	1.13
CA K	53.7100	3.49
TI K	5.6000	0.43
FE K	215.0400	25.58
ZN K	143.1800	35.25
TOTAL		100.00

Figure 58. EDAX of untreated primer(Figure 2). Zinc content of coating shows 35%, consistent with nominal chemistry of zinc-based primer.

EDAX Results
Sample 13
Paint Remaining on Grit Blasted Surface

```
INTE-%-ZAF:
LABEL =
15-JUN-94    08:47:50
  100.000 LIVE SECONDS
Ku= 20.0    TILT=30 .    TKOFF=33
            ZAF CORRECTION
```

ELEM	K	z	A	F
NAK	0.0023	1.076	0.159	1.001
ALK	0.0029	1.070	0.330	1.003
SIK	0.0534	1.101	0.453	1.002
P K	0.0259	1.074	0.527	1.002
PBM	0.005S	0.764	0.882	1.000
AGL	0.0168	0.888	0.915	1.011
CAK	0.0053	1.078	0.B83	1.025
TIK	0.0056	0.985	0.943	1.068
FEK	0.6043	0.986	0.989	1.017
ZNK	0.1615	0.958	0.954	1.001

ELEM	CPS	WT% ELEM
NA K	2.6300	1.32
AL K	6.1100	0.82
S1 K	132.7900	10.69
P K	49.5497	4.57
PB M	4.5300	0.82
AG L	12.8217	2.05
CA K	8.7000	0.54
TI K	7.9300	0.57
FE K	508.2200	60.95
ZN K	70.8600	17.67
TOTAL		100.00

Figure 59. EDAX of residual inorganic zinc primer on grit blasted suflace (Figure 8). Zinc content of coating shows 17.7%.

EDAX Results of Laser Processed Material
Sample 32
Large Melted Island on Material Surface

INTE-%-ZAF:
LABEL =
15-JUN-94 08:06:42
100.000 LIVE SECONDS
Ku= 20.0 TILT= 30. TKOFF=33.
ZAF CORRECTION

ELEM	K	Z	A	F
NAK	0.0009	1.084	0.144	1.000
SIK	0.0252	1.109	0.4S1	1.002
P K	0.0183	1.082	0.553	1.003
AGL	0.0191	0.89S	0.944	1.01S
CAK	0.0049	1.08S	0.899	i.034
SML	0.0013	0.829	1.047	1.004
MNK	0.0116	0.974	0.989	1.004
FEK	0.7944	0.993	0.994	1.006
ZNK	0.0666	0.965	0.940	1.000

ELEM	CPS	WT % ELEM
NA K	0.9829	0.57
S1 K	60.0200	s.03
P K	33.4200	3.04
AG L	13.9500	2.23
CA K	7.7100	0.48
SM L	0.s194	0.15
ml K	11.0700	1.19
FE K	639.9100	79.97
ZN K	27.9700	7.55
TOTAL		100.00

Figure 60. EDM of residual primer after laser stripping at 1350W, 60 ipm(l.5m/min) (Figure 12). Zinc content of melted material shows 7.3 Y'.

IX. DISCUSSION OF RESULTS

Although there are two commercially available devices capable of cleaning three edges simultaneously, (recirculating grit blasters, and triple wire-brush units), neither of these machines has seen wide acceptance for their intended purpose. Possible reasons for this are explored below.

Referring again to Table I, the triple-brush machine can clean preconstruction primer from plate surfaces at a rate of 5-10 fpm (1.5-3 m/nin.), as has been verified in limited production use at Bath Iron Works. The equipment is reliable and robust, and performs cleaning at a rate on a par with, or faster than, other rotary-wheel equipment (see Table III). As stated earlier, quality of cleaning is not equivalent to grit blasting, but maybe adequate for most applications. The main disadvantage of the triple brush unit is its weight (60 lb. [27.2kg]), which makes it virtually impossible to operate on the edges of plates lying flat. The weight requires two persons for lifting and positioning (according to OSHA standards) and this negates some of the speed advantage. While load balancers or other devices could alleviate this proble~ some loss of flexibility in use would result. It is possible that some weight savings could be made by redesigning the framework, but some of the inherent ruggedness of the existing tool might be sacrificed. Further, any attempt to incorporate a vacuum shroud could add weight and bulk.

For three-edge grit blasting, the quoted maximum rate of 20 @m (6. 1 mhnin) was never achieved, and with steel grit, speeds averaged less than 5 fpm (1.5 m/min) (see Table II and III). The main disadvantage of the grit blasting equipment is this slow speed, but there are other problems with the available equipment. The initial configuration of the three-edge gun at a weight of 14 lb. (6.4 kg), was somewhat lighter than the current model from ABB, which weighs in excess of 16 lb. (7.3 kg). Beyond the weight of the unit, the stiffness and bulk of the vacuum hose made the system awkward and cumbersome. It is possible that materials now available for hoses could provide some greater degree of flexibility with no penalty in weight or even a potential savings in weight. The blast head itself could perhaps use high-molecular weight polymers instead of metals for certain components, allowing some weight savings with adequate resistance to abrasion. Since cleaning speed is dependent on the amount of grit supplied to the nozzles, a greater capacity feed unit and larger nozzles might offer improvement. Balancing of all of these considerations is certainly a challenge, yet the equipment in its present form does not appeal to potential users.

A further difficulty in using the grit blasting heads was trying to maintain an even feed rate of the head along the workpiece. The early version had no guide rollers, which meant that the operator was required to keep the gun in alignment with all three edges, and also that the jaws of the gun could snag on rough flame cut surfaces. Misalignment would result in erratic cleaning patterns, and rough edges would lead to slower and more erratic feed rates, in addition to causing more strain on the operator.

The addition of guide rollers did make moving the head along the plate edges easier with the later versions than it was the old model. Although this was a step in the right direction, it did not fully solve the problem of erratic feeding and introduced some new problems. First, the guide. rollers are plain steel cylinders with a single guide flange, rotating around a stationary steel pin.

The lack of bearings or bushings, and the presence of light rust on the pins and rollers, caused uneven friction and contributed to erratic feeding of the machines tested during this program. The amount of friction was such that the gun could not be pushed firmly into the workpiece, negating some of the advantage of having the rollers. Some sort of dry-type (lubricants would "hold" grit and dust) bushing should be used to reduce friction. The relative position of the guide rollers can be seen in Figure 4 on page 7. Even though this is a relatively new head, the roller in view already has a considerable film of rust established.

Second, the single flange on the guide roller, while allowing the operator to rest the weight of the gun, establishes the alignment of the gun's nozzles relative to the plate. Figure 61 shows a schematic of the orientation of the blast nozzles to the plate edge. The dashed lines indicate the intersection of the guide roller flange vertically (V) and horizontally (H) with the plate edge. As show the blast pattern is optimized, providing even cleaning of all three edges. It can also be inferred that if the plate is thicker than show and the guide roller is registered on the upper edge, the resulting pattern will be insufficient on the lower edge of the plate. For each plate thickness, the roller position would have to be adjusted to keep the cleaning pattern consistent. Limited vertical adjustments could be made, but the configuration of the guide roller mounting screws and wing nuts was such that this was a difficult operation.

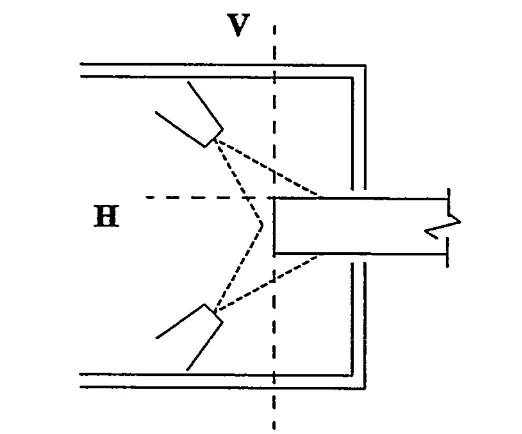


Figure 61. Ideal alignment of nozzles

Any rotating motion of the gun changes the relative alignment of the nozzles to the plate, resulting in an uneven pattern. The deviation which can occur as the head is rotated about the intersection of the guide roller with the plate edge is depicted by Figure 62. The angle and the gap in the brush seals can increase the chance of grit spillage as well. Since the friction of the rollers did not allow the gun to be held firmly against the plate edge, wobbling of the head occurred frequently during the tests as the head was moved along the plate edge. Referring once more to Figure 4 on page 7, the guide roller is not fully engaged against the edge of the part being cleaned, an 8x10# I/T, and the radius area of the flange stub still has gray preconstruction primer showing.

A furhter implication of the fixed alignment of guide roller to the blast nozzles is that achieving a sufficient cleaning pattern on beveled plate edges is rendered much more difficult. Ideally, the guide roller should intersect the point of the bevel, or "nose" of the weld prep. Merely inverting the head (Figure 63) helps little, since the entire weight of the head would now have to be borne by the operator. Further, the control valve may have to be moved to provide

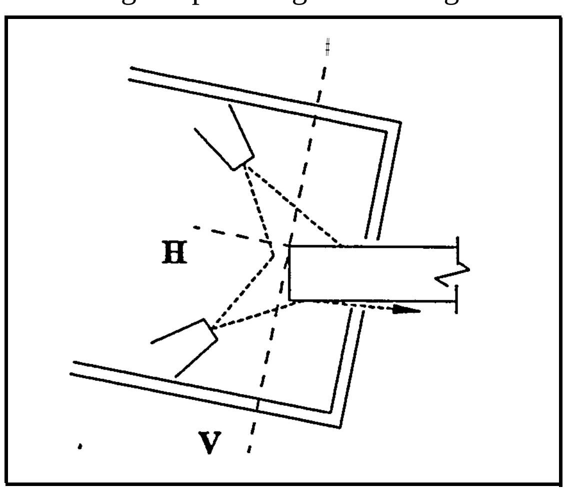


Figure 62. Misalignment caused by tilt

comfortable operation. Figure 63 also shows that with the gun inverted, the required top area of flat plate sueface will not be exposed to the blast pattern, since the bevel face and top have a greater area needing cleaning than the underside. What is needed is the ability to adjust the guide rollers in the horizontal plane as well as the vertical.

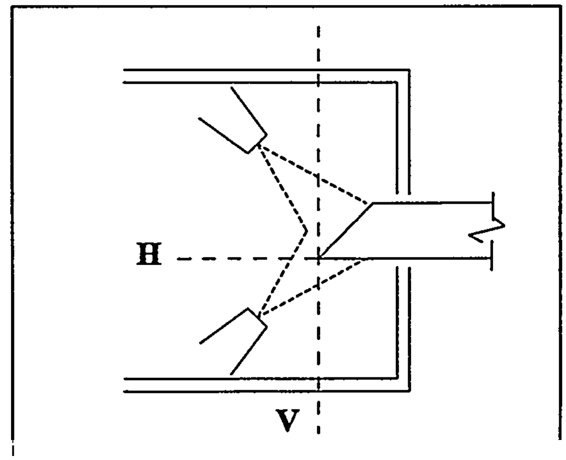


Figure 63. Alignment at beveled edge, head inverted

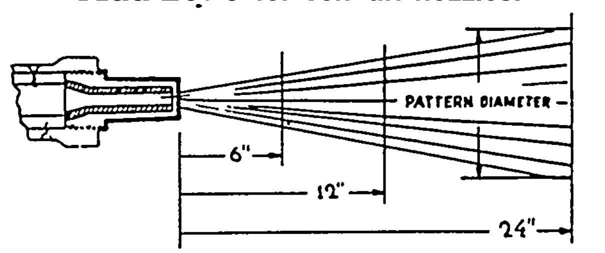
An alternative to the adjustable guide roller would be to provide adjustable nozzle positions. Another approach would be to have a hinged jaw, which moved both nozzles evenly as the head was adjusted for different thicknesses. Nozzle position both toward and away from the plate edge would have to be adjustable to allow adequate pattern coverage for beveled plates. Any of these concepts introduce more movable parts to the system, and makes set-up of the machine more difficult.

A further alternative approach would be the use of an "air bearing," a series of ports with low pressure compressed air sufficient to balance the force on the top, bottom and edge. These could make the system virtually frictionless, and have some damping quality at the same time. Orientation of such ports could provide an "air curtain" effect, helping to force stray grit particles back into the head. This might require a larger capacity vacuum system, and the air pressure required might add to the noise level.

The sketch and table printed in Figure 64 describes the effect which nozzle diameter and distance to the workpiece have on the size of the blast pattern. In the three-edge blast heads, this is a compromise between effective pattern and the overall size of the unit. For the tests using the Kelco System 3/16 in. (4.7mm) nozzles were used, yielding a 1/2 in. (12.7mm) pattern from each nozzle. Increased nozzle distance would yield a wider pattern, but would also make the head bulkier and might require a larger vacuum unit to completely scavenge all the waste products from the larger chamber.

Nozzle Pattern Diameters
at Various Distances (Inches)

Add 2070 **for ven~uri nozzles.**



Regulate the feed of sand so it can just be seen leaving the nozzle.

NOZZLE SERIES	NOZZLE SIZE (Sixteenths of an Inch)	DISTANCE OF NOZZLE FROM WORK (Inches) 6"	12"	24"
KTM 3" Long	2	1 Dia.	1½ Dia.	3 Dia.
	3	1	2	4½
	4	1½	2½	5
	5	2	4	7½
	6	2½	5	9½
	7	2½	5½	11
	8	3	6½	13
	10	4	8	16
KTL 6" Long	3	½ Dia.	1 Dia.	2½ Dia.
	4	1	1½	3
	5	1	2	4
	6	1½	2½	5
	7	1½	3	6
	8	2	3½	7
	10	2½	4	8

Figure 64. Blast pattern vs. nozzle distance
(Courtesy: Kelco Sales&Engineering)

X. REFERENCES

1. Mil-Std 1689A Naval Sea Systems Command, Department of the Navy. 1990

2. Rules for Building and Classing Vessels, American Bureau of Shipping. 1990

3. Mil-Std 278F, Naval Sea Systems Command, Department of the Navy. 1987

4. Structural Welding Code, D-1.1, American Welding Society. 1993

5. George, John R. "Report on Tests of Blast Cleaning to Prepare Steel Plate and Stiffener Edges for Welding." July, 1995

6. Denney, P. E., Applied Research Laboratory, Pennsylvania State University, personal conversation, 3/8/94.

7. Hedriks-Eckerman, M. L., B. Engstrom, and E. Arias: "Thermal Degradation Products of Steel Protective Paints." Am. Ind. Hyg. Assoc. J. 51(4):241-244 (1990)

APPENDIX A: LIST OF RESOURCES

Product/Service	Organization/Address	Contact Person/Phone
Grit Blasting Equipment/Consulting		
	KeIco Sales & Engineering 11936 Front Street Norwalk CA 90650	Tracy Polley, President (310)-868-9861 FAX (3 10)-864-2534
	John R George, Engineering Consultant 1201 E. Fairhaven #14N Santa Ana, 92701	John R George (714)-532-1131
	Vacu-B1ast International Woodson House, Ajax Avenue SlougkBerks,SL14DJ, England, U.K.	E. J. Nye, Export Director 011-44-753-526511 FAX 01144-753-538093
	ABB Air Preheater- Ehrsarn Blast Systems, Inc. PO Box 339 Abilene, KS 67410	Linda Harrold, Application Engr. (800)-255-7910 FAX (913)-263-3932
CrystalGrit	ARDEA International PC) Box 9012 Spring, TX 77387	Dieter Ehlers, Pres. (713)-367-6065 FAX (713)-292-7947
Laser Processing Development Work		
	Applied Research Laboratory, PennState University PO Box 30, State College, PA 16804	Paul Denney, Department Head (814)-865-2934 FAX (814) 863-2934
Lasers	Hobart Laser Products 332 Earhart Way Liverrnore, CA 94550	Tim Webber (510)-294-8167 FAX (510)-294-9128
Scannning Eleetron Microscopy		
	Mjollnir Metallurgical 4415 Portola Road Atascadcro, CA 93422	Dr. Daniel W. Walsh (805)461-3060 FAX (805)-756+503
$C0_2$ Pellet Blasting Equipment and Supplies		
	Cryogenesis, Inc. 2140 Scranton Road Cleveland, OH 44113	James Becker, President (216)-696-8797 FAX (216)A96-8794
High Pressure Water Blasting Equipment		
	National Liquid Blasters, Inc. 29830 Beck Road Wixom, MI 48393-0908	James Boomis (810)-624-5555 FAX (810)-624-0908
Multiple Wire Brush Equipment		
	Desco Manufacturing Company, Inc. 1445 Cowles Street Long Beach, CA 90813	Paul Fallcrs (301)478-0504 (800)-337-2648
HVOF Torch	Hanson Machine Company 28 Sweatt Street Boscawen, NH 03303	Kenneth Hanson, Owner (603)753-9094
Vacuum Shrouded Needle Guns		
	PenTeL Inc. 1026 Fourth Avenue Coraopolis, PA 15108-1659	Bradley P. Fuller (412)-262-0725 FAX (412)-2624731

ABSTRACT

Steel used in fabrication and assembly operations in shipyards is often coated with primers to pressure the steel prior to the application of finish coating systems. There are many occasions when these coatings must be removed in way of welding and this coating removal is traditionally performed using manual grinding, sanding, and wire brushing methods. Alternatives to these traditional methods were studied at eight separate locations in order to identify and evaluate the occupational safety and health stressors that operators of this equipment maybe exposed to and the identified hazards were compared to those associated with the traditional coating removal techniques employed at one shipyard. Recommendations for controlling identified hazards were also developed. Hazards specifically evaluated included exposures to noise, airborne contaminants, physical hazards such as those from figitive blast particulate, and ergonomic stresses. Operations evaluated included simultaneous three edge blast cleaning, laser stripping, vacuum shrouded needle gunning, oxy-fiel stripping, and carbon dioxide bead blasting.

Simultaneous three edge blast cleaning technology virtually eliminated operator exposure to airborne contaminants while exposures to noise, ergonomic hazards, and physical hazards were all similar to those presented by traditional coating removal operations. Facilities that employ this technology should veri~ compliance with OSHA policies and standards for noise, ergonomics, and personal protective equipment. Carbon dioxide bead blasting noise measurements indicated exposures well in excess of those presented by the traditional methods and exposures to airborne contaminants (carbon dioxide) potentially presented more serious exposure hazards than exposures to airborne contaminants (iron, zinc, lead, and cadmium) typical of traditional methods. Ergonomic and physical hazards were essentially similar to those presented by traditional methods. Laser stripping was shown to virtually eliminate operator exposure to airborne contaminants. The use of vacuum shrouded needle guns and oxy-fuel stripping presented noise exposures similar to those presented by traditional coating removal methods.

INTRODUCTION

Steel that is used in shipyard fabrication and assembly processes is usually coated with a primer that is designed to protect the steel prior to the application of the finish coating systems. There are several different types of primers that maybe applied. Some primers, such as most epoxy primers, must be removed in weld areas prior to welding operations. Other primers, such as inorganic zinc preconstruction primers, can oflen be left in place in way of welding, However, certain types of steel and certain types of welds will always require any coatings to be removed in way of weIding and there are some cases where coating removal prior to welding may yield weld efficiency and/or quality benefits.

This coating removal is traditionally performed using manual grinding, sanding, and wire brushing methods and the coating must often be removed from the top, bottom, and edge surfaces of the steel. Manual blast cleaning equipment which cleans all three surfaces

simultaneously and recovers and recirculates the blast abrasive may be a feasible alternative to the above described methods. Other potential alternatives include removing coating with laser energy, vacuum shrouded needle guns, oxy-fuel flame stripping, and carbon dioxide bead blasting. NSRP project N7-92-2 compared the productivity of the traditional methods of plate edge weld preparation with that of these alternative methods with emphasis on simultaneous three-edge blast cleaning. The project also compared the occupational safety and health hazards associated with the alternative techniques to those associated with traditional techniques and the results of this safety and health evaluation are contained in this report. Exhaustive safety and health evaluations were not conducted at each site. The depth of each evaluation was determined based on the goals of the NSRP project and the costs and benefits of evaluating the various types of hazards at the various sites.

The United States Department of Labor, Occupational Safety and Health Administration (OSHA) establishes the safety and health regulations that United States employers are required to comply with. Included in these regulations is a set of permissible exposure limits (PELs) which are maximum concentrations of airborne contaminants to which employees may be exposed. Most of the PELs are expressed as eight hour time weighted averages (TWA8) which indicate the average concentrations of particular contaminants that employees are allowed to be exposed to during an eight hour period. When exposures exceed these limits, then employers must implement engineering controls to lower the exposures to below the PELs. If it is not feasible to lower exposures to below the PELs using engineering controls, then employers must use administrative controls and/or personal protective equipment that are effective at lowering employee exposures to concentrations below the PELs. Some airborne contaminants also have action levels (ALs) which are concentrations of airborne contaminants that trigger certain activities such as continued exposure monitoring, medical surveillance, and training. PELs and ALs apply not only to airborne contaminants but also to employee exposure to noise.

OSHA has established general regulations indicating that employers must protect employees from physical hazards such as sharp, hot, or cold objects, which can cause cuts and bums, and flying objects that can become embedded in the eyes. Employers are required to evaluate their operations, determine how these standards apply, and take appropriate actions.

OSHA does not have a standard to address eve~ possible occupational hazard. However, where there are recognized hazards that can cause serious physical injury or illness, OSHA can cite and fine employers under the General Duty clause of the OSHA Act of 1970. OSHA does not have a standard that addresses ergonomic hazards. These hazards, however, are recognized and well understood by industry, government institutions, and the medical community and they are capable of causing serious injury. Therefore, OSHA can require that employers take appropriate actions to abate ergonomic hazards.

In addition to occupational hazards, environmental hazards can be associated with coating removal operations. One such hazard is associated with the disposal of the waste products

from coating removal operations. Waste disposal is primarily regulated by state and local authorities and thus, consultation with these authorities is necessary to determine required practices since these vary widely.

MATERIALS AND METHODS

Data was collected at eight locations and specific hazards were evaluated in each of the locations in accordance with table 1.

Table 1. Locations visited and hazards evaluated during the occupational safety and health hazard study associated with NSRP project N7-92-2.

Company	Address	Dates	operation Evaluated	Hazards Evaluated
KeIco Sales and Engineering	Norwalk, CA	05126194	Blast cleaning the edges of tec bars using a manually operated simultaneous three-edge blasting system equipped with a vacuum operated abrasive recovery and recirculating system. Steel grit and aluminum oxide abrasives were in usc during the evaluation.	Noise Airborne - iron - zinc - lead - cadmium Ergonomics Physical hazards
Vacu-Blast International	slough, England, UK	10/1 9494	Blast cleaning the edges of tee bars using a manually operated simultaneous three-edge blasting system equipped with a vacuum operated abrasive recovery and recirculating system. Metal abrasives were in use during the evaluation.	Noise Ergonomics Physical hazards
ABB Raymond	Abilene, KS Job site Herington, KS	04118J95	Blast cleaning the edges of tee bars using a manually operated simultaneous three-edge blasting system equipped with a vacuum operated abrasive recovery and recirculating system. Metril abrasives were in use during the evaluation.	Noise Ergonomics Physical hazards
Harland and Wolff	Belfast, Northern Ireland, UK	**10/20/94**	Blast cleaning the edges of tee bars using a automatic, fixed simultaneous three-edge blasting system equipped with a vacuum operated abrasive recovery and recirculating system. Metal abrasives were in usc during the evaluation.	Noise Physical hazards
Hobart Laser Products	Livcrmorc, CA	03/29194	Laser beam stripping of various zinc based preconstruction primers (Zn PCPS).	Airbome - iron - zinc - lead - cadmium - chromium
PenTek	Pittsburgh,, PA	08130/94	RemovaI of Zn PCP using a vacuum shrouded needle gun.	Noise
Hanson Machine	Boscawcn, NH	10/07/94	RernovaI of Zn PCP using high velocity oxy-fuel flame stripping.	Noise
Clyogcncnis	Cleveland, OH	04126195	Blast cleaning Zn PCP and epoxy PCP from two edges of tee bars using $C0_2$ bead blasting.	Noise Airborne COZ Ergonomics Physical hazards

The following techniques were used to evaluate the specified hazards:

Airborne Metals:

All airborne metal samples were collected on 37 millimeter mixed cellulose ester fiber filter cassettes placed either in the breathing zone of the operator or in an area where it was desired to determine the airborne concentration of the subject contaminants. Ambient air was drawn through the cassettes using Mine Safety Appliances Company, Escort personal sampling pumps. The flow rates of the pumps were calibrated before and after each sampling session using a Gilian Instruments Corporation, Primay F1OW Calibrator (PN 800268),2 -30 LPM sensor block (PN D800288), and Bubble Generator (PN D800285).

The filters were analyzed for metals using the following methods as prescribed by the National Institute for Occupational Safety and Health (NIOSH): Iron - NIOSH 7200, Zinc - NIOSH 7030, Lead - NIOSH 7082, Cadmium - NIOSH 7048, Chromium - NIOSH 7024. Monitoring was conducted for specified time periods and time weighted average exposure levels were calculated and reported for the time sampled.

Airborne Carbon Dioxide:

Screening samples for airborne carbon dioxide (COZ) were obtained using a Drager gas detector pump model 31 fitted with Drager CH 23501COZ gas detection tubes. All samples were collected in the breathing zone of the operator and sampling data were reported as the concentration of airborne COZ present in the breathing zone at the time the sample was collected.

Noise:

All noise measurements were obtained using Ametek MK-3 Audio Dosimeters with the microphones placed either in the operators' hearing zones or in areas where it was desired to determine the ambient noise levels. The dosimeters were calibrated with an Ametek AC-94 Acoustic Calibrator before and after each sampling session. Time weighted average noise levels were obtained for both personal exposures and ambient background noise. Screening samples which indicate the noise levels at the instant the samples were collected were also obtained. Time weighted average noise measurements were assigned sample numbers while screening samples were not.

Air contaminant and noise data that were gathered per the above processes were then compared to OSHA requirements as well as appropriate industrial hygiene and safety engineering principles in order to determine what practices users of this technology may have to implement in order to assure compliant and safe operations. OSHA reference values are indicated in table 2.

Table 2. OSHA permissible exposure limits and action levels for evaluated agents.

Agent	Permissible Exposure Limit	Action Level
Iron Oxide	10 mg/m^3	none
Zinc	15 mg/m^3	none
Lead	50 pg/m^3	30 pg/m^3
Cadmium	5.0 pg/m^3	2.5 pg/m^3
Chromium	0.5 mg/m^3	none
Carbon dioxide	5000 ppm	none
Noise	90 dBA	85 dBA

Where: mg/m^3 = milligrams per cubic meter
pg/m^3 = micrograms per cubic meter
ppm = parts of contaminant per million parts of air (vol/vol)
dBA = decibels in the A weighted scale

<u>Ergonomics</u>:

Ergonomic stressors were evaluated by visually observing and video taping operators to identify postures and motions that are likely to cause injury from repeated or prolonged exposure.

<u>Physical Hazards</u>:

Hazards that are likely to cause physical injury to operators were evaluated by visually observing the operation and identifying possible sources of injury.

<u>Historical Data</u>:

Historical data for operator exposures to the above described hazards during traditional coating removal operations were obtained from a shipyard which employs these techniques.

<u>Waste Disposal</u>:

A sample of waste blast fines was taken from the classifier waste receptacle after simultaneous three edge blast cleaning of steel coated with about 0.8 roils of inorganic zinc preconstruction primer. A toxicity characteristic leaching procedure (TCLP) analysis was performed on the sample to determine the concentrations of RCRA regulated metals. The values were compared with RCRA reference values in order to determine proper waste disposal procedures.

RESULTS

Kelco Sales and Engineering

Occupational exposures to airborne contaminants, noise, ergonomic hazards, and physical hazards were evaluated during blast cleaning of tee bars using simultaneous three edge blast cleaning and recovery equipment.

Air contaminants and noise exposures:

Operator exposures to airborne contaminants were determined to be well below the OSHA PELs while exposures to noise were found to be in excess of the PEL. The data from this sampling are summarized in table 3. These data indicate that facilities employing this technology should conduct noise monitoring to determine noise levels for their operations and then comply with OSHA standard 29 CFR 1910.95 Occupational Noise Exposure as appropriate.

Table 3. Summary of airborne contaminant and noise exposure measurements obtained during simultaneous three edge blast cleaning at Kelco Sales and Engineering. Exposure levels are reported as time weighted averages of the time sampled.

Sample Number	Sample Type (personal/area)	Time Sampled (minutes)	Agent	Exposure Level (mg/m^3)
T		237	Iron	0.071
			Zinc	0.008
			Lead	BDL
			Cadmium	BDL
94146-2	Area	238	Iron	0.035
			Zinc	0.002
			Lead	BDL
			Cadmium	BDL
94146-1N	Personal	257	Noise	98.2 dBA
94146-2N	Area	121	Noise	80.7 dBA

where: mg/m^3 = milligrams per cubic meter
BDL = below detectable limits
dBA = decibels in the A-weighted scale

Ergonomic hazards:

The operator was required to maintain a static upper body posture while operating this equipment. The lower back was exposed to compression forces from the operator holding

up the weight of the blast head and hose. The lower back was also exposed to shear forces from the operator dragging the hoses as work progressed down the length of the stock. These forces could result in sprains and strains to the lower back and shoulders as well as the possibility of disc injury if performed over a period of time. Static, prolonged gripping was performed with the possibility of wrist deviation. This could expose the operator to risk factors that have been associated with the development of cumulative trauma disorders. These data indicate that facilities employing this technology should have their operations evaluated by a qualified ergonomist and implement controls that will mitigate ergonomic hazards in order to preclude ergonomic injuries.

Physical hazards:

Fugitive abrasive particles were frequently emitted from the blast head, especially when the blast head was tilted at an angle that was not neutral to the surface of the steel being cleaned. It was determined that these fugitive abrasive particles are likely to strike the eyes causing injury. Facilities employing this technology should evaluate their operations for this hazard and implement a personal protective equipment (PPE) program for eye protection as appropriate.

Vacu-Blast International:

Occupational exposures to, noise, ergonomic hazards, and physical hazards were evaluated during blast cleaning of tee bars using simultaneous three edge blast cleaning and recovery equipment.

Noise exposures:

A set of screening samples were obtained during the operation of Vacu-Blast simultaneous three edge blast cleaning and recovery equipment. The data from this sampling are summarized in table 4. These data indicate that facilities employing this technology should conduct noise monitoring to determine noise levels for their operations and then comply with OSHA standard 29 CFR 1910.95 Occupational Noise Exposure as appropriate.

Table 4. Summary of noise screening measurements obtained during simultaneous three edge blast cleaning at Vacu-Blast International.

Location of Sample	Noise levels dBA	Comments
Background noise in center of shop.	‘c 75.0	None.
Adjacent to Vacu-Blast machine.	94-96	Measurement obtained while operator was blasting 3/4” steel plate several yards away.
Two feet away from blast head.	93-96	3/4” steel plate inserted into head. Vacu-Blast machine on, no blasting taking place.
Two feet away from blast head.	98-101	1/16” steel plate inserted into head. Vacu-Blast machine on, no blasting taking place.
Hearing zone of operator.	104-107	While blasting 1/16” steel.
Two feet away from blast head.	94-97	1/4” steel plate inserted into head. Vacu-Blast machine on, no blasting taking place.
Hearing zone of operator.	99-102	While blasting 1/4” steel plate.
Two feet away from blast head.	88-90	Blast head resting on top of 114” steel plate.

Ergonomic hazards:

Consistent with those described for Kelco Sales and Engineering.

Physical hazards:

Consistent with those described for Kelco Sales and Engineering.

ABB Raymond:

Occupational exposures to noise, ergonomic hazards, and physical hazards were evaluated during blast cleaning of tee bars using simuhaneous three edge blast cleaning and recovered equipment.

Noise exposures:

A set of screening sample were obtained during the operation of ABB Raymond Blast System simultaneous three edge blast cleaning and recovery equipment. The data from this sampling are summarized in table 5. These data indicate that facilities employing this technology should conduct noise monitoring to determine noise levels for their operations and then comply with OSHA standard 29 CFR 1910.95 Occupational Noise Exposure as appropriate.

Table 5. Summary of noise screening measurements obtained during simultaneous three edge blast cleaning at ABB Raymond.

Location of Sample	Noise levels dBA	Comments
Back ground noise levels in shot).	<75	None
Two to Three feet from blast machine	75-80	Machine running, no blasting taking place.
> three feet from blast machine,	<75	Machine running, no blasting taking place.
One foot from blast head.	88-91	Machine running, no blasting taking place.
Hearing zone of operator.	104-115	Blasting the web of tee bar. Noise levels started at 115 dBA and drops to 104-105 after 10 seconds.
Hearing zone of operator.	105-118	Blasting the flange of tee bar with web up. Noise levels started at 118 dBA and drops to 105-106 after 10 seconds.
Hearing zone of operator.	101-110	Blasting the flange of tee bar with web down. Noise levels started at 110 dBA and drops to 101-103 after 10 seconds.
Hearing zone of operator.	102-110	Blasting the web of tee bar with larger head. Noise levels started at 110 dBA and drops to 103-104 after 10 seconds.

Ergonomic hazarad

Consistent with those described for Kelco Sales and Engineering.

Physical hazards:

Consistent with those described for Kelco Sales and Engineering.

<u>Harland and Wolff</u>:

Occupational exposures to noise and physical hazards were evaluated during operation of a fixed simultaneous three edge blasting and recovery system. Material was conveyed through the blast head via a roller conveyor. The head was enclosed in a booth that was intended to reduce emissions of noise.

Noise exposure:

A time-weighted average noise exposure was obtained for the operator and screening samples were obtained for ambient noise levels. These data are summarized in tables 6 and 7. These data indicate that facilities employing this technology should conduct noise monitoring to determine noise levels for their operations and then comply with OSHA standard 29 CFR 1910.95 Occupational Noise Exposure as appropriate.

Table 6. Summary of noise exposure measurement obtained during the operation of fixed simultaneous three edge blast cleaning equipment at Harland and Wolff. Exposure level is reported as the time weighted average of the time sampled.

Sample Number	Samp!e Type (personal/area)	Time Sampled (minutes)	Agent	Exposure Level (dBA)
94292-IN	personal	50	Noise	101.1

Table 7. Summary of screening samples obtained during the operation of fixed simultaneous three edge blast cleaning equipment at Harland and Wolff.

Location of Sample	Noise levels dBA	Comments
Background noise levels in shop.	81-89	None.
Three feet from blast head.	105-107	Blasting taking place.

Hobart Laser Products:

Occupational exposures to airborne contaminants were evaluated during removal o f zinc based preconstruction primer using a laser beam stripping process.

Air contaminants exposures:

Time weighted average exposures for personal and area samples were obtained. These data are summarized in table 8. The data indicate that operator exposures to airborne contaminants can be expected to be well below the PELs.

Table 8. Summary of airborne contaminants exposure measurements obtained during laser stripping at Hobart Laser Products. Exposure levels are reported as time weighted averages of the time sampled.

Sample Number	Sample Type (personal/area)	Time Sampled (minutes	Agent	Exposure Level (mg/m^3)
94088-1	Personal	30	cadmium	BDL
			chrome	BDL
			iron	0.027 mg/m^3
			lead	BDL
			zinc	0.058 m,g/m^3
94088-2	area	148	cadmium	BDL
			chrome	BDL
			iron	0.03 mg/m^3
			lead	BDL
			zinc	0.008 mg/m^3

PenTek:

Occupational exposures to noise were obtained where a vacuum shrouded needie gun was used to remove inorganic zinc preconstruction primer from steel.

Noise exposure:

Screening samples were obtained for operator exposure and ambient noise levels. These data are summarized in table 9. These data indicate that facilities employing this technology should conduct noise monitoring to determine noise levels for their operations and then comply with OSHA standard 29 CFR 1910.95 Occupational Noise Exposure as appropriate.

Table 9. Summary of noise screening measurements obtained during operation of vacuum shrouded needle gun at PenTek.

Location of Sample	Noise levels dBA	Comments
Background noise levels in shop.	88-89	With compressor only running. The compressor was outside near an open door.
Hearing zone of operator	104.9	During needle gunning.

Hanson Machine:

Occupational exposures to noise were obtained during the removal of inorganic zinc preconstruction primer from steel using oxy-fbel flame stripping.

Noise exposure:

Time weighted average and screening samples were obtained for operator noise exposure and ambient noise levels. These data are summarized in tables 10 and 11. These data indicate that facilities employing this technology should conduct noise monitoring to determine noise levels for their operations and then comply with OSHA standard 29 CFR 1910.95 Occupational Noise Exposure as appropriate.

Table 10. Summary of noise exposure measurement obtained during high velocity oxy-fuel flame stripping at Hanson Machine. Exposure level is reported as the time weighted average of the time sampled.

Sample Number	Sample Type (personal/area)	Time Sampled (minutes)	Agent	Exposure Level (dBA)
94280-lN	personal	34	Noise	94.7

Table 11. Summary of noise screening measurement obtained during high velocity oxy-fuel flame stripping at Hanson Machine.

Location of Sample	Noise levels dBA	Comments
Background noise levels in shop.	<75	None.

Cryogenesis:

Occupational exposures to airborne CO_2 and noise were evaluated during the removal of inorganic zinc and epoxy primers from steel using $C0_2$ bead blasting.

Carbon dioxide sampling:

Screening samples for airborne CO_2 concentrations were obtained during CO_2 bead blasting. These data are summarized in table 12. These limited data indicate that exposures are not likely to exceed the PEL under the conditions evaluated. However, performing this operation in enclosed and confined spaces may present exposures in excess of the PEL and present very hazardous conditions. Such operations must be evaluated by competent occupational safety and health professional prior to implementation.

Table 12. Summary of airborne $C0_2$ screening measurements obtained during CO_2 blasting at Cryogenesis.

Location of Sample	CO_2 levels (ppm)	Comments
Breathing zone of operator	1,200	Blasting at 100 psi.
Breathing zone of operator	1,400	Blasting epoxy coated tee bar at 80 psi.
Breathing zone of operator	700	Blasting epoxy coated tee bar at 125 psi.
Breathing zone of operator	700	Blasting epoxy coated tee bar at 195 psi.

Noise exposures:

Screening samples for noise were obtained during $C0_2$ bead blasting. These data are summarized in table 13. These data indicate that facilities employing this technology should conduct noise monitoring to determine noise levels for their operations and then comply with OSHA standard 29 CFR 1910.95 <u>Occupational</u> <u>Noise</u> <u>Exposure</u> as appropriate.

Table 13. Summary of noise screening measurements obtained during $C0_2$ blasting at Cryogenesis.

Location of Sample	Noise levels (dBA)	Comments
Back ground noise levels in shop.	78-82	None
Hearing zone of operator	117-119	Blasting at 100 psi.
Hearing zone of operator	107-108	Blasting epoxy coated tee bar at 80 psi.
Hearing zone of operator	124-125	Blasting Zn PCP coated tee bar at 125 psi.
Hearing zone of operator	125-127	Blasting epoxy coated tee bar at 125 psi.
Hearing zone of operator	127- 130.5	Blasting epoxv coated tee bar at 195 psi.

Ergonomic hazards:

The equipment used in this process was relatively light weight, did not vibrate, and offered little resistance to movement. There appeared to be a low risk of ergonomic injury from using this equipment. However, the manner in which the work is set up relative to the operator could expose the operator to ergonomic stresses if the work is set up such that the operator must maintain awkward and static postures for extended periods.

Physical hazards:

The operator was exposed to hazards created by the ricochet of blasted surface impurities and coating fragments which could become embedded in the eyes, It is possible for the operator to be exposed to cold injury hazards from handling $C0_2$ pellets as well exposed surfaces of the cold blasting nozzle. Facilities employing this technology should evaluate

their operations for these hazards and implement PPE programs for eye and hand protection as appropriate.

Bath Tron Works:

A simultaneous three edge blast cleaning and recovery system was evaluated for proper disposal of waste fines.

Waste Disposal:

TCLP analysis of waste fines was conducted in order to determine proper disposal methods. These data, which are summarized in table 14, indicate that this waste should be disposed of as special waste. Grinding swarf that is produced during coating removal operations employing traditional methods should also be disposed of in the same manner.

Table 14. Summary of TCLP data for waste blast fines obtained from simultaneous three edge blast cleaning operations conducted at Bath Iron Works.

Metal	TCLP results (mg/L)	RegulatoV limit (mg/L)
Asenic	<0.04	5.0
Barium	1.0	100.0
Cadmium	<().() 1	1.0
Chromium	<0.2	5.0
Lead	<0.1	5.0
Mercury	<().()()2	0.2
Selenium	<().()4	1.0
Silver	<0.1	5.0

DISCUSSION

Simultaneous Three Edge Blast Cleaning (Kelco Sales and Engineering, Vacu-Blast International, ABB Raymod, and Harland and WOlff:

Simultaneous three edge blast cleaning systems equipped with vacuum powered grit recovery and recirculation systems were evaluated in four locations. In three of these locations the system was manually operated and in the fourth the system was fixed and operated automatically. The hazards presented by these four operations were essentially similar with some minor differences in the automated system. The great advantage of

these systems is that operator exposure to airborne contaminants from the coating removal operation is virtually eliminated. Data gathered at Kelco Sales and Engineering suggest that exposures to airborne iron and zinc during this process can be expected to be four to five orders of magnitude below the OSHA permissible exposure limits and exposures to lead and cadmium to be below the limits of detection. Although exposures to airborne contaminants resulting from this operation are expected to be well below the PELs, it is still prudent to conduct personal exposure monitoring upon initial implementation of this process and periodically thereafter. The purpose of this monitoring is to assure that the equipment is functioning properly and being used properly. Additionally, documenting low exposures is as valuable as documenting high exposures.

Data collected at one shipyard that employs the traditional methods of coating removal indicates that airborne concentrations of metallic air contaminants often exceed the OSHA PELs during these processes. Additionally, these concentrations tend to increase if the space in which the work is being performed is more confined.

Noise data from all four locations suggest that noise is likely to present hazards to operators of this equipment and that proper measures to control these hazards and comply with OSHA regulation 29 CFR 1910.95 must be implemented. In order to meet these goals, feasible engineering controls will have to be established to reduce operator exposure to noise to below an eight hour time-weighted average exposure of 90 dBA (9o dBA TWA8). If it is not possible to reduce noise to these levels using engineering controls, then administrative controls (limiting the duration of an individual's exposure) or the use of hearing protectors capable of reducing the effective exposure to below 90 dBA TWA8 will have to be implemented. In the case of manually operated systems, there are very few if any engineering controls that can be implemented to reduce noise exposures. In the case of the automated process, it is likely that the blast head could be enclosed in a sound absorbing enclosure that reduces noise levels outside of the enclosure to below 90 dBA. Although OSHA requires engineering controls, administrative controls, and hearing protectors to be implemented when exposures exceed 90 dBA TWA8, it is recommended by the American Conference of Governmental Industrial Hygienist and other qualified agencies and individuals that these measures be implemented whenever exposures exceed 85 dBA TW&. Other programs that are required by OSHA to be implemented whenever exposures exceed the AL of 85 dBA TWA_8 include written hearing conservation programs, exposure monitoring programs, audiometric testing programs, and training programs.

Data collected at one shipyard that employs the traditional methods of coating removal indicates that personne! performing coating removal employing these methods are exposed to noise at about the same levels that can be expected from using simultaneous three edge blast cleaning equipment.

Data obtained at Kelco Sales and Engineering, Vacu-Blast International, and ABB Raymond suggest that personnel manually operating three edge simultaneous blast cleaning systems are potentially exposed to ergonomic stressors that are likely to cause

injury. Operators may be required to maintain static, awkward postures while holding heavy equipment which may expose them to risks of serious soft tissue injury to the neck, back, shoulders, arms, wrists, and hands. Several controls can be implemented in order to mitigate these risks. Operators should be trained in the following areas: causes of ergonomic injury, recognition of the signs and symptoms of ergonomic injury, and methods used to prevent and treat ergonomic injury. The stresses on the neck, shou!ders, arms, hands and wrists of the operators should be reduced by incorporating a padded sling into the design of the blast head. Other tool design changes that reduce the effective weight of the tool for the operator should be developed and evaluated for effectiveness. These design changes may be specific to each site where the tool is used as operational conditions may vary substantially from site to site. Whenever possible, work areas should be designed so that the work is at such a height that the operator maintains neutral (joints are neither flexed nor extended), erect postures rather that stooping over. A period of work hardening (a gradual increase in the duration of exposure) should be allowed whenever an operator is initially assigned to the operation of this equipment as well as after vacations, sicknesses, and other absences. Operators should be required to participate in frequent stretch, flex, and rest breaks. Finally and most importantly, a professional qualified in ergonomic evaluations should evaluate operations at any site that is implementing this blast cleaning technology. The above described ergonomic hazards are virtually eliminated at the Harland and Wolff site where the blast head was in a fixed location and operated automatically.

Data collected at one shipyard that employs the traditional methods of coating removal indicate that personnel performing coating removal employing these methods are also potentially exposed to ergonomic stressors that are capable of causing serious injury. The specific stressors that the traditional methods present are somewhat different than the stressors presented by the equipment evaluated in this study and perhaps present a slightly higher degree or injury risk to the operators.

The physical hazards presented by simultaneous three edge blast cleaning and recovery technology were consistent at all four sites. Even the automated facility allowed escape of stray blast particles that could strike the operators eyes. This, however, could have been mitigated if the enclosure was more effective. An enclosure that effectively reduces noise levels will generally be tight enough such that emission of blast particles from the enclosure will not occur. The physical hazards associated with this technology are also similar to the hazards that are known to exist for the traditional methods of coating removal.

Laser Beam Stripping(Hobart Laser Products):

The only hazard evaluated in this process was exposure to airborne metals. The data from this evaluation suggest that exposures to airborne metals during laser stripping of coatings will not exceed the OSHA PELs. However, initial and periodic monitoring of exposures to these agents is recommended in order to assure that the equipment is functioning properly as well as to document the low levels of exposure. Although the only hazard

evaluated in this process was exposure to airborne metals, this does not imply that other hazards do not exist. Other hazards that should be considered where this technology is implemented includes exposure of the skin and eyes to laser energy, electrical hazards, and materials handling hazards to name a few.

Like simultaneous three edge blast cleaning, this method of coating removal compares favorably with traditional methods with respect to operator exposure to airborne contaminants.

Vacuum Shrouded Needle Gun (PentTek):

The only hazard evaluated in this location was exposure to noise. Additionally, only screening samples were collected. Although very litt!e data were collected, they can be useful in predicting the exposures of operators of this equipment if there is knowledge of the duty cycle of the operation. When the equipment is running, noise levels are likely to be in excess of 100 dBA. When the equipment is not running, noise levels will be that of the ambient environment. As the percentage of run time to stop time increases, the noise exposures experienced by the operators will increase to approach the noise levels produced when the equipment is running. Given that at least four hours of run time could be expected for and eight hour shift, the noise exposures can be predicted to exceed 90 dBA TWA_8. Therefore, the same noise control requirements that apply for simultaneous blast cleaning equipment would apply to this technology. Additionally, the noise exposures that can be predicted from these data are simi!ar to the noise levels that are typical of traditional coating removal methods.

Oxy-fuel Stripping (Hanson Machine):

The only hazard evaluated in this location was exposure to noise. Additionally, only one screening sample and a brief time-weighted average sample were collected. Like the data that were collected for vacuum shrouded needle gunning, these limited data can be usefil if one has knowledge of the duty cycle. Data from this evaluation suggests that there is the potential for operators to be exposed above the OSHA PEL for noise. Therefore, facilities that implement this technology will be required to conduct initial monitoring and take appropriate steps based on this monitoring.

Carbon Dioxide Bead Blasting (Cryogenesis):

Data collected during this evaluation indicates that CO_2 bead blasting is likely to produce noise exposures well in excess of the OSHA PEL. Depending on the blast pressures used, these noise levels may be so high that any available hearing protection may not have a high enough noise reduction rating (NRR) to reduce operator noise exposures to below the PEL. Ear plugs and ear muffs are tested and assigned NRRs which are expressed in decibe!s (dB). A typical NRR for a very effective ear plug is 30 dB. This does not mean that the plug reduces the noise exposure by 30 dBA. There area number of methods for determining the exposure under the hearing protector based on the NRR of that hearing

protector and these methods are either published or referenced in appendix B of OSHA standard 29 CFR 1910.95. One such method is to monitor an operator's noise exposure with a dosimeter that measures the exposure in dBA. Subtract 7dB from the NRR of the hearing protector being evaluated. Subtract this value from the time weighted average exposure measurement determined with the dosimeter and this is the operators exposure to noise under the hearing protector. For example, if an operator's exposure to noise is 125 dBA TWA8 and the operator is wearing an ear plug with an NIUt of 30 then the operators noise exposure under the plug will be 125 dBA -23 dBA = 102 dBA which is still well above the PEL of 90 dBA. It is also important to note that when double hearing protection is worn (muffs over plugs), the NRRs of the two hearing protectors are not additive. Chapter 4 of the OSHA Technical Manual states that to determine the NRR of double hearing protection, add 5 dB to the NRR of the higher rated protector. This NRR can then be used in the above equation to determine the exposures under the double hearing protection. It appears that operator rotation will be required to reduce exposures to noise to below 90 dBA TWA8. Noise levels produced by this operation appear to be well in excess of those produced during traditional coating removal methods. Noise exposures during open nozzle grit blasting can be expected to range form 100 dBA to 115 dBA. Therefore, noise levels produced during CO_2 bead blasting can exceed those produced during grit blasting depending on the pressures used.

Potential operator exposures to CO_2 were evaluated by collecting screening samples under only one set of conditions. These data have significant limitations on predicting exposures under general use conditions but some beneficial information can be derived. These data suggest that when this equipment is used in very well ventilated areas, operator exposures to CO_2 are not likely to exceed the PEL. These data are not sufficient to predict exposures in enclosed and confined spaces. In these types of areas, ventilation is generally limited and air contaminants produced by various operations tend to accumulate to dangerous levels. The most serious hazard that this technology presents is the accumulation of CO_2 in enclosed and confined spaces. CO_2 can displace oxygen where ventilation is limited, and thus expose operators to fatal asphyxiation hazards. It is absolutely imperative that any operations involving this technology be evaluated by a qualified occupational safety and health professional upon each implementation. Although traditional coating removal methods are likely to present concentrations of airborne contaminants above the PELs especially when working in enclosed or confined areas, these exposures, if not properly controlled, are likely to produce ill health effects only afler a relatively long term exposure whereas exposures to CO_2 during CO_2 bead blasting in poorly ventilated areas are capable of causing death from just one exposure.

The CO_2 bead blasting equipment that was evaluated had no provisions for preventing removed coating and surface contaminants from becoming airborne. These particulate may present airborne contaminant exposure hazards. Further study is required to determine the scope of this potential hazard.

The risk of ergonomic injury associated with CO_2 bead blasting appears to be relatively low when compared to traditional coating removal operations. Care must still be

exercised to set up the work area properly so that operators are not required to maintain awkward, static postures. Also, engineering controls and/or personal protective equipment must be implemented in order to protect operators from cold injury due to contact with the cold blast nozzle and CO_2 pellets.

The physical hazards associated with $C0_2$ bead blasting are essentially similar to those of traditional coating removal operations with the exception that CO_2 bead blasting could present cold injury hazards to the hands of operators if they are required to handle $C0_2$ pellets without proper equipment and or PPE.

One overall conclusion that can be expressed for all of the technologies evaluated is that hazards presented by these technologies can vary significantly form site-to-site depending on local variables. For this reason, it is impossible to determine from this or any other report, the nature and magnitude of all hazards that can exist at any one site. Wherever these technologies are implemented, qualified occupational safety and health professionals should be part of the process implementation team in order to assure that these processes will be safe and compliant. There are other hazards that will likely require control. Some such hazards may not be directly related to the above described technologies but maybe presented by associated processes. For instance, operators will likely be required to handle steel materials. These materials can have sharp, rough edges that can cut the hands. Material can also fall from heights to cause injury to various body parts. These associated processes should also be evaluated for hazards and appropriate controls should be implemented.

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